N89-70840

NASA CONTRACTOR REPORT 177392

Large Deployable Reflector (LDR)
Analysis of Space Station Interface Requirements

W. H. Alff
L. W. Bandermann

CONTRACT NAS2- 11862

December 1985

NASA

FOREWORD

This report summarizes the analyses and conclusions for a space station - LDR interface definition study carried out by Lockheed Missiles and Space Co., Inc., Research and Development Division, under a modification of contract NAS2-11862: Large Deployable Reflector (LDR) System Concept and Technology Definition Study.

The report consists of the annotated Vugraphs of the final presentations made by LMSC at NASA Ames Research Center (ARC) and Johnson Space Flight Center (JFC).

LMSC gratefully acknowledges the guidance and helpful critiques by the ARC study monitor and technical personnel.

W. Alff, Program Manager
L. Banderman, Study Leader

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LARGE DEPLOYABLE REFLECTOR ANALYSIS OF SPACE STATION INTERFACE REQUIREMENTS

FINAL REVIEW

18 NOVEMBER 1985 NASA AMES RESEARCH CENTER

20 NOVEMBER 1985 NASA JOHNSON SPACE FLIGHT CENTER

CONTRACT NAS2-11862

Research & Development Division
LOCKHEED MISSILES & SPACE COMPANY, INC.
Palo Alto, California 94304

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INTRODUCTION

W. ALFF

STUDY PLAN

The study involved 6 individual tasks: The benefits of LDR using the space station-rather than the Orbiter - as an assembly and servicing facility were identified in Task 1. The emphasis of the study was on deriving the space station/interface requirements (Tasks 2 to 4), particularly those which are LDR unique. Finally, in Tasks 5 & 6, a concept and the initial requirements for an experiment demonstrating several critical LDR technologies were developed. This experiment can be carried out on the Shuttle at the Space Station.

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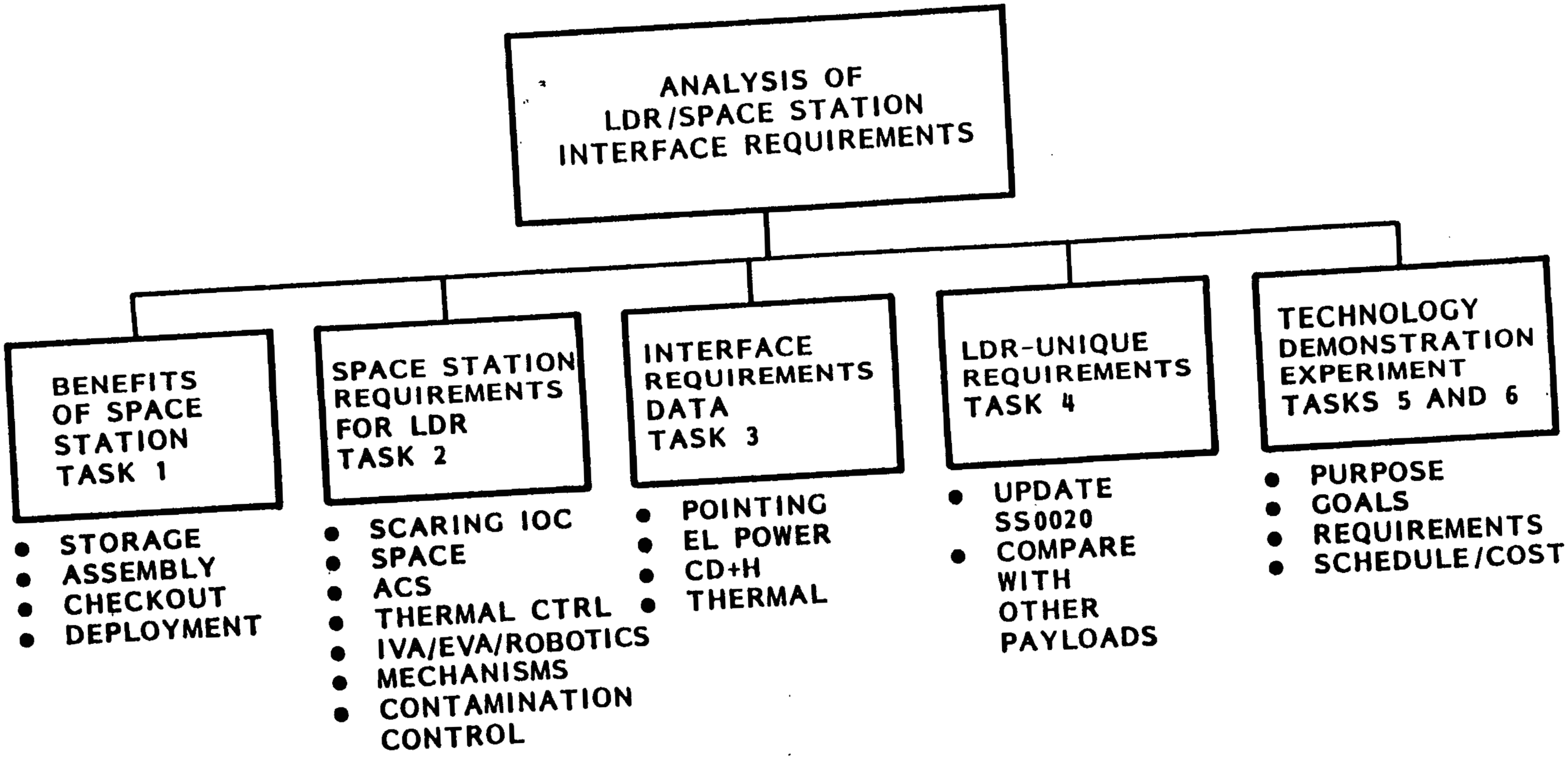
STUDY PLAN



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BENEFITS OF SPACE STATION USE AND CONCLUSIONS

L. BANDERMANN

BENEFITS OF SPACE STATION USE FOR LDR (2 charts)

Because of its size, several shuttle loads are required to transport LDR to its assembly station. The assembly station is preferably a low altitutde orbit to minimize transportation costs and exposure of assembly personnel to cosmic radiation, while the operational orbit of LDR is approximately 750 km. Assembly and checkout from the Orbiter involves severe time constraints, pushes the LDR design toward automated deployment and requires the first load to be a self-sustaining spacecraft. With the space sation as assembly station, many of these constraints are loosened, and the design of LDR would be slewed toward a combination of man-in-the-loop (EVA and IVA) plus robotics, with much generic hard and software and facilities available. The OMV will be available from the station whereas, with Orbiter assembly of LDR, it would have to be brought to the orbiter from the station.

Servicing facilities of the type required by LDR will have been developed to some extent by the LDR is assembled at space station: for example, SIRTF will already have undergone one cryogen refurbishment. Again, on the station time lines are more flexible, and manpower and facilities are more readily available than from the Orbiter.

Survey of the payloads scheduled for assembly and servicing at the station shows that LDR not unique in any of its requirements, with the possible exception of the locale for cryogen fill. Payload size and weight are larger for some of the other payloads, although LDR is one of the earliest large payloads and may exceed the others in terms of overall complexity and assembly precision.

BENEFITS OF SPACE STATION USE FOR LDR (1 OF 2)

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- STORAGE PRIOR TO ASSEMBLY AND DEPLOYMENT
  - TRANSPORT OF LDR PARTS IN SEVERAL SHUTTLE TRIPS (PIGGY BACK)
  - TIME LINE AND SCHEDULE FLEXIBLE (SOFT DEPLOYMENT)
  - FIRST LOAD DOES NOT REQUIRE COMPLETE SPACECRAFT (INCLUDING ACS, ELECTRICAL POWER, AND PROPULSION)
  - LIFTS POSSIBLE DESIGN CONSTRAINTS
  - AVOIDS COST OF TRACKING/MONITORING OF FIRST LOAD; EXTENDS DEPLOYMENT SCHEDULE
- ASSEMBLY AND CHECKOUT
  - NO CRITICAL TIME LINES; MAJOR GLITCHES NOT CRITICAL
  - LESS AUTOMATION REQUIRED; LESS DEPLOYMENT HARDWARE
  - GENERIC ASSEMBLY AIDS, HARDWARE AND CONTROL SOFTWARE AVAILABLE
  - INCREASED MANPOWER (18 ON GROWTH VERSION)
  - ORBITER NOT PRESENT; LESS CONTAMINATION
- TRANSPORTATION TO ORBIT
  - OMV AVAILABLE AND CAPABLE FOR ORBIT TRANSFER (TO AND FRO)
  - SMALL ALTITUDE DIFFERENCE; SMALL TRANSPORT COST

BENEFITS OF SPACE STATION USE FOR LDR (2 OF 2)

- SERVICING
  - ESTABLISHED CAPABILITIES AND PROCEDURES (INSTRUMENT CHANGEOUT AND CRYOGEN TRANSFER)
  - TEST EQUIPMENT
  - MORE TIME
  - SUPPLIES AND REPLACEMENT PARTS BROUGHT TO SPACE STATION WHEN CONVENIENT AND COST EFFECTIVE

- – LDR NOT THE DRIVING PAYLOAD FOR ASSEMBLY AND SERVICING AT THE STATION
- – TRUSSES OF STATION MAKE ASSEMBLY MUCH EASIER AND FASTER THAN IF ON SHUTTLE
  - -- EVA TIME
  - -- USE OF ROBOTICS

IMPACT ON SPACE STATION (2 charts)

The space station design has not yet been frozen, thus an assessment of the impact of accomodating LDR (storage, assembly/checkout and servicing) on the structure and various space station subsystem requirements is preliminary in nature. The assessment depends in particular on the assumed assembly location of LDR.

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IMPACT ON SPACE STATION (1 OF 2)

- IOC SCARING
  - LDR STORAGE
  - LDR ASSEMBLY AND CHECKOUT
  - LDR ASSEMBLY AND CHECKOUT AIDS AND FACILITIES
  - LDR SUPPLIES
  - LDR SERVICING EQUIPMENT, SUPPLIES
- GN&C
  - POINTING
  - VIBRATION CONTROL
  - STATION KEEPING
- THERMAL CONTROL
  - RADIATORS (POINTING, SIZE)
  - SPACE STATION ATTITUDE DURING LDR CHECKOUT (IF AT STATION)
- ELECTRICAL POWER
  - PEAK AND AVERAGE POWER
  - POWER DISTRIBUTION (MOBILE PLATFORMS)

IMPACT ON SPACE STATION (2)

A location was picked based on the latest space station concept, namely the dual-keel concept. Of this location we found the impact of LDR on key space station subsystems to be small. For example, in the area of GN&C, the dual-keel space station is gravity gradient unstable about all three axes and therefore continuously under active attitude control. LDR does not change the situation nor add significant to the control requirements, primarily because LDR is not far from the space station C.G. - Electrical power requirements are currently not well defined for LDR, primarily since it is uncertain if LDR will have an active cryosystem (mechanical cooler) or rely mainly on passive cooling. - There is a requirement for increased drag makeup since LDR, because of its low mass/area ratio, will increase the orbit decay rate of the station. The magnitude of the effect depends on the time LDR will be fully deployed at the station. - A simple holding structure is required for LDR for assembly and initial checkout. The need for a large hangar was not identified since the advantages of such a hangar are unclear and the disadvantages (cost impact) may be considerable.

Contamination of LDR was found non-ciritcal since LDR is a "warm" telescope; however, it was assumed that LDR checkout was carried out between, not during, OMV and shuttle arrivals and departures.

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IMPACT ON SPACE STATION (2 OF 2)

- PROPULSION
  - ACCOMMODATE FOR INCREASED DRAG
- C&DH
  - INTERNAL AND EXTERNAL COMMUNICATIONS
  - DATA STORAGE AND TRANSFER DURING LDR ASSEMBLY AND CHECKOUT
- OPERATIONS
  - IMPACT ON SCHEDULES OF OTHER PAYLOADS ON SPACE STATION
  - IMPACT ON SHUTTLE AND OMV ARRIVAL AND DEPARTURES SCHEDULE
- STRUCTURES AND MECHANISMS
  - HOLDING, STORAGE, AND ASSEMBLY
  - RMS, MRMS, AND ROBOTICS
- CONTAMINATION CONTROL (ACTIVE AND PASSIVE)
  - PARTICULATES
  - GASES

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REQUIREMENTS

- CONFIGURATION

D. GARDNER

WHICH WILL BE THE SPACE STATION CONFIGURATION?

NASA's Space Station Phase B Studies are currently reviewing all aspects of mission requirements, sub-systems concepts, operational performance, costs, reliability traffic models, etc., with a view to making a firm recommendation on the configuration to be carried forward into the Phase C-D competition.

The initial design of the early concept of the gravity-gradient class is shown to the left of this sketch, this concept has been replaced by the dual-keel approach, two variants of which are shown here. These unsetted issues therefore make it difficult to select a preferred location for LDR assembly & check-out. However, for this study, LMSC has selected the dual keel concept and all anlaysis & EVA/assembly activities are based on it.

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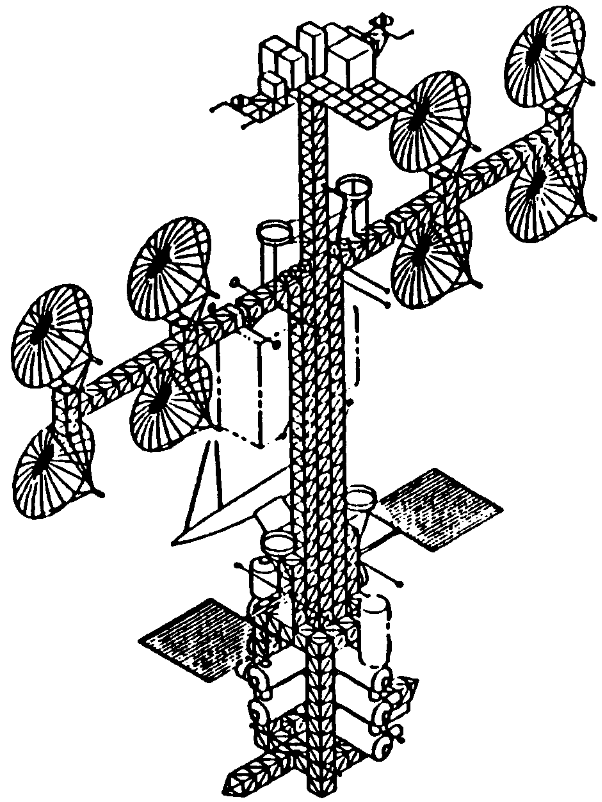
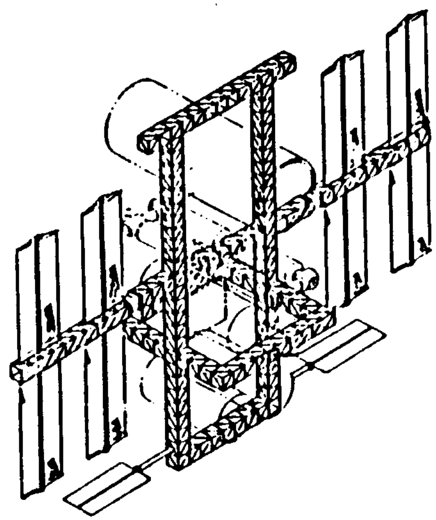
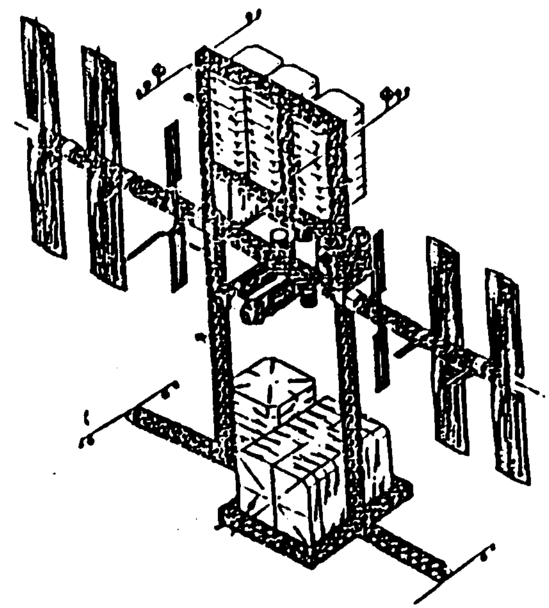
WHICH WILL BE THE SPACE STATION CONFIGURATION ?







REFERENCE SPACE STATION

This drawing depicts the concept LMSC has based it's current analyses for:

- Flight Control Interfaces
- Thermal Control Interfaces
- Contamination Control
- Logistics
- STS Cargo Bay/Mass Properties Interfaces
- Crew Systems Interfaces
- Structural/Mechanical Interfaces
- LDR Build-Up
- LDR Check-Out
- LDR Deployment

The primary structure of the space station is assumed to be built-up of a series of 9 foot cubes, with diagonal cross bracking all constructed of graphite epoxy tubing approximately 2.0 inches diameter.

Payloads would be attached at a variety of locations on this structure with the majority being located on the upper & lower booms.

A free path on the forward & aft faces of the structure is assumed for the delivery of LDR components using the mobile remote manipulator system (MRMS).

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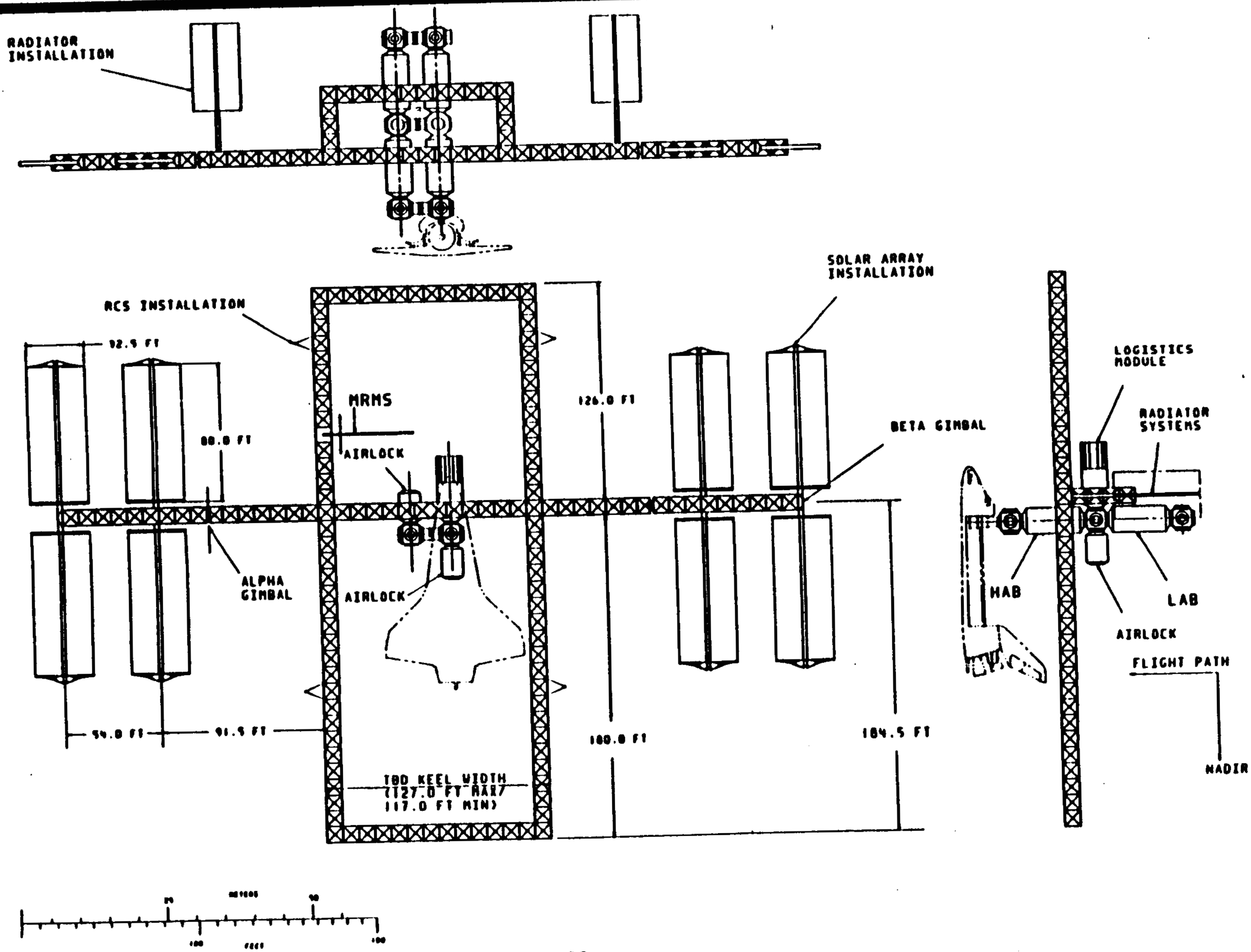
REFERENCE SPACE STATION



ASSEMBLY SITE POSSIBILITIES

This chart depicts several conceptual options for the LDR assembly site.

The preferred location is shown on the upper left figure where maximum accessibility to the LDR is available from the surrounding structure. However, the central location would only be available in the abscence of the large OMV & OTV servicing hangars shown in the lower picture, a conflict of scheduling either the hangars or the LDR onto the space station would become a restriction not easily resolved due to future planning unknowns.

If the central location should be selected the assembly site would require rotational capability to provide clearance for the shuttle vertical stablilizer, this capability would be used also for deployment of the LDR.

The concept on the far right provides for assembly closest to the station center of gravity, however, this location would probably be too disruptive to operations around the manned habitations and laboratory modules.

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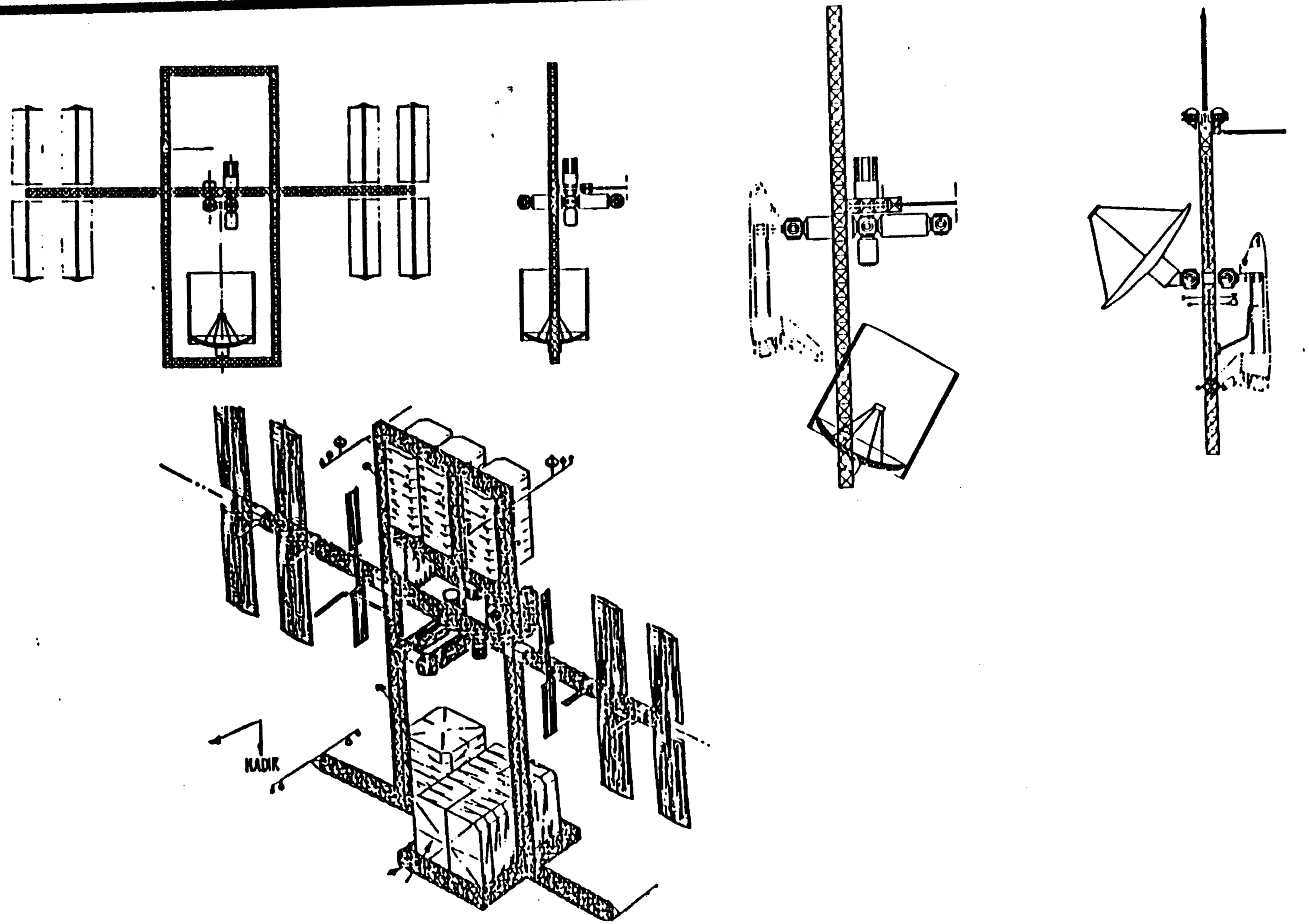
ASSEMBLY SITE POSSIBILITIES



LDR ASSEMBLY SITE

The site selected for LDR is shown here.

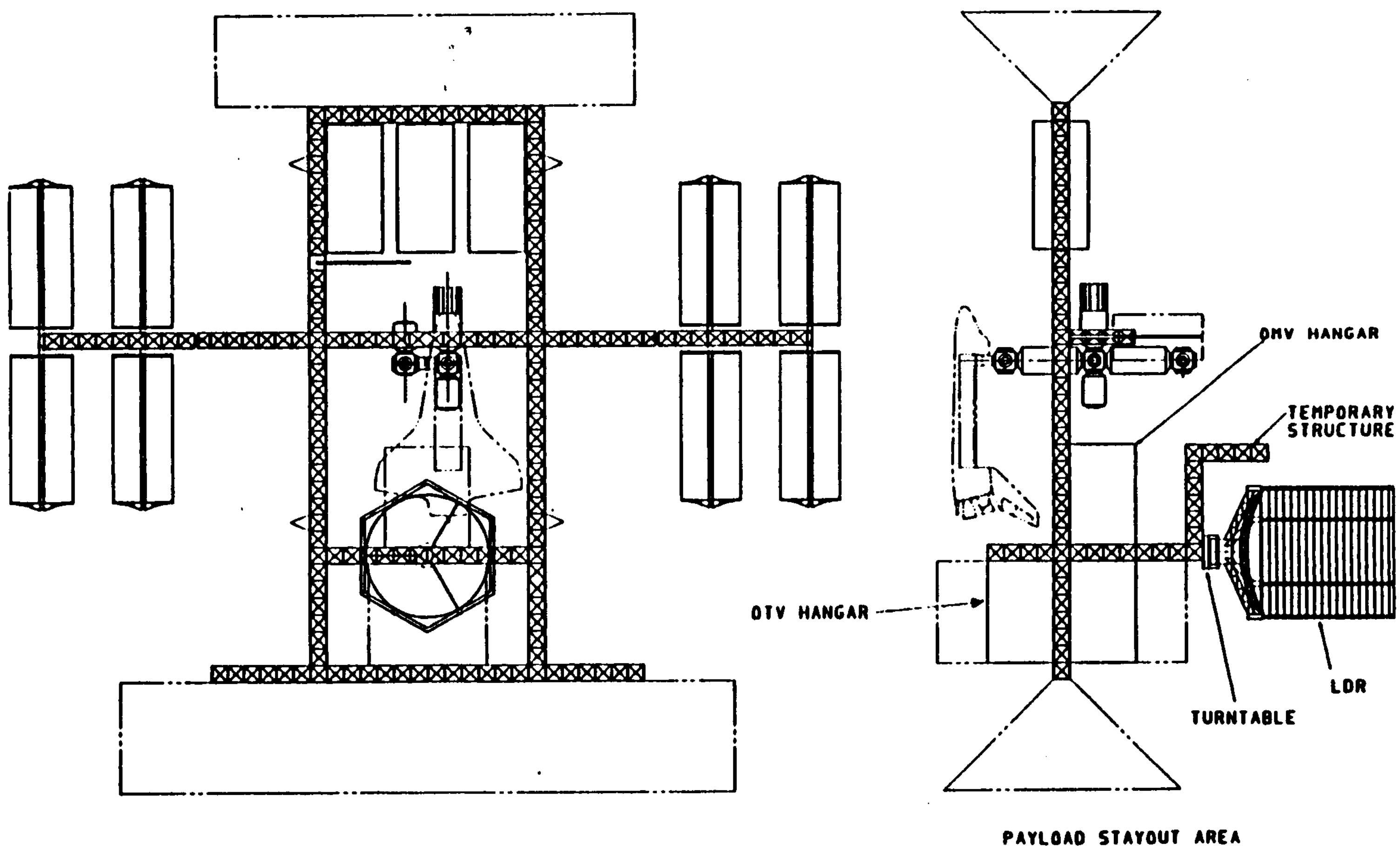
The primary support structure/turntable is attached to a short extension of a primary truss supporting the OMV & OTV hangars.

Attached to this extension is a temporary truss structure which is used by the MRMS and EVA astronauts to reach above and around the basic mirror assembly.

The OTV hangar shown is one of many ideas proposed, it starts out as an 81 foot long structure & with growth would extend to 135 feet, as shown by the outline shown in phantom.

Future studies for LDR assembly should include the possibility of providing the necessary hardpoints, storage areas, servicing points, as an integral part of the OTV/OMV hangar structures.

LDR ASSEMBLY SITE



LDR - SUNSHADE CONCEPT

The proposed sunshade concept shown here consists of six deployable 'curtains' mounted on a substructure attached to the body of the spacecraft and isolated from the mirror assembly.

The concertina type deployables are based upon the flight proven (Space Shuttle Mission 41D) Lockheed SAFE (Solar Array Flight Experiment) concept, the solar array blankets ofcourse would be replaced with aluminum sheets or other foldable material to provide the sunshade capability.

All of the mechanisms for deployment and retraction have been developed and would only require minor modification to meet the LDR mission. However techniques must be developed for sealing the edges at the intersections of individual blankets.

Primary advantages to the concept include the lightweight and minimum stowed volume requirements, and minimal eva monitoring. A light proof diaphragm would be required over the entire aft end of this design (not shown in this sketch).

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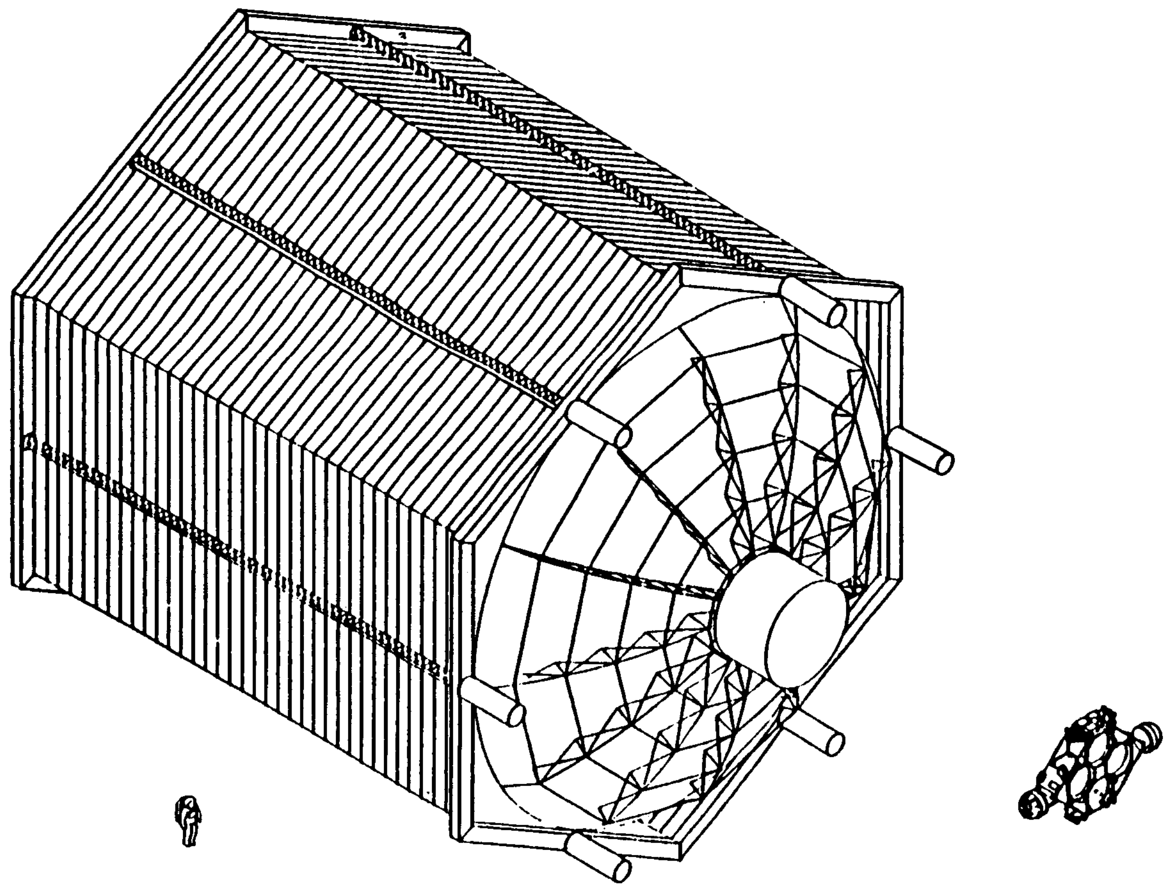
LDR – SUNSHADE CONCEPT



LDR - CONFIGURATION ('B') (SEMI-ERECTABLE)

This sketch summarizes the Lockheed proposed semi-erectable LDR configuration.

The erectable mirror support structure, of graphite epoxy tubes, is attached at its center to the spacecraft center body. Also attached to the center body are six pre-assembled outrigger beams which support the deployable curtain canisters and also the smallest solar array canisters.

The secondary optics are attached to a tripod structure supported at the edges of the primary mirror assembly.

The basic assembly is 28 meters long and encompasses the 20 meter disk, the preliminary estimated weight for the entire assembly is approximately 34,500 Kgs.

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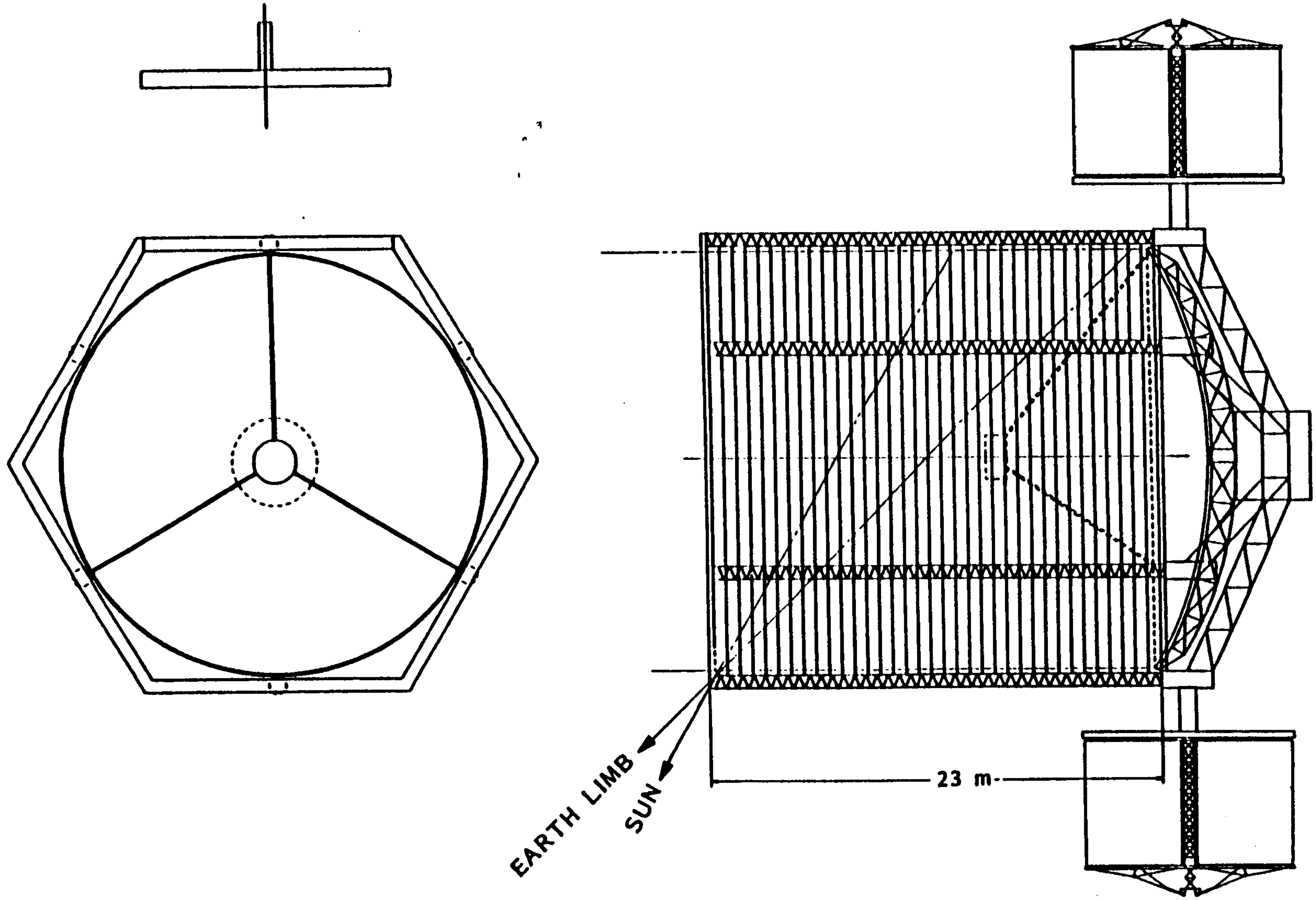
LDR - CONFIGURATION 'B' (SEMI-ERECTABLE)



ALTERNATE LDR SUNSHADE CONCEPT

This sunshade concept is based on a deployment system of six folding longerons and six folding octagonal rings.

Stowed with the folded trusswork would be a kapton membrane which unfolds automatically as the structural members are deployed; once fully deployed the entire structure is stablished by a series of tension crosswires.

The entire sunshade structure is supported from the spacecraft and is isolated from the mirror assembly.

Aluminized kapton membranes stretched across both ends of the assembly to provide contamination protection, the forward end being removable during LDR operations.

It is estimated that this concept, along with the LDR spacecraft would require two STS launches.

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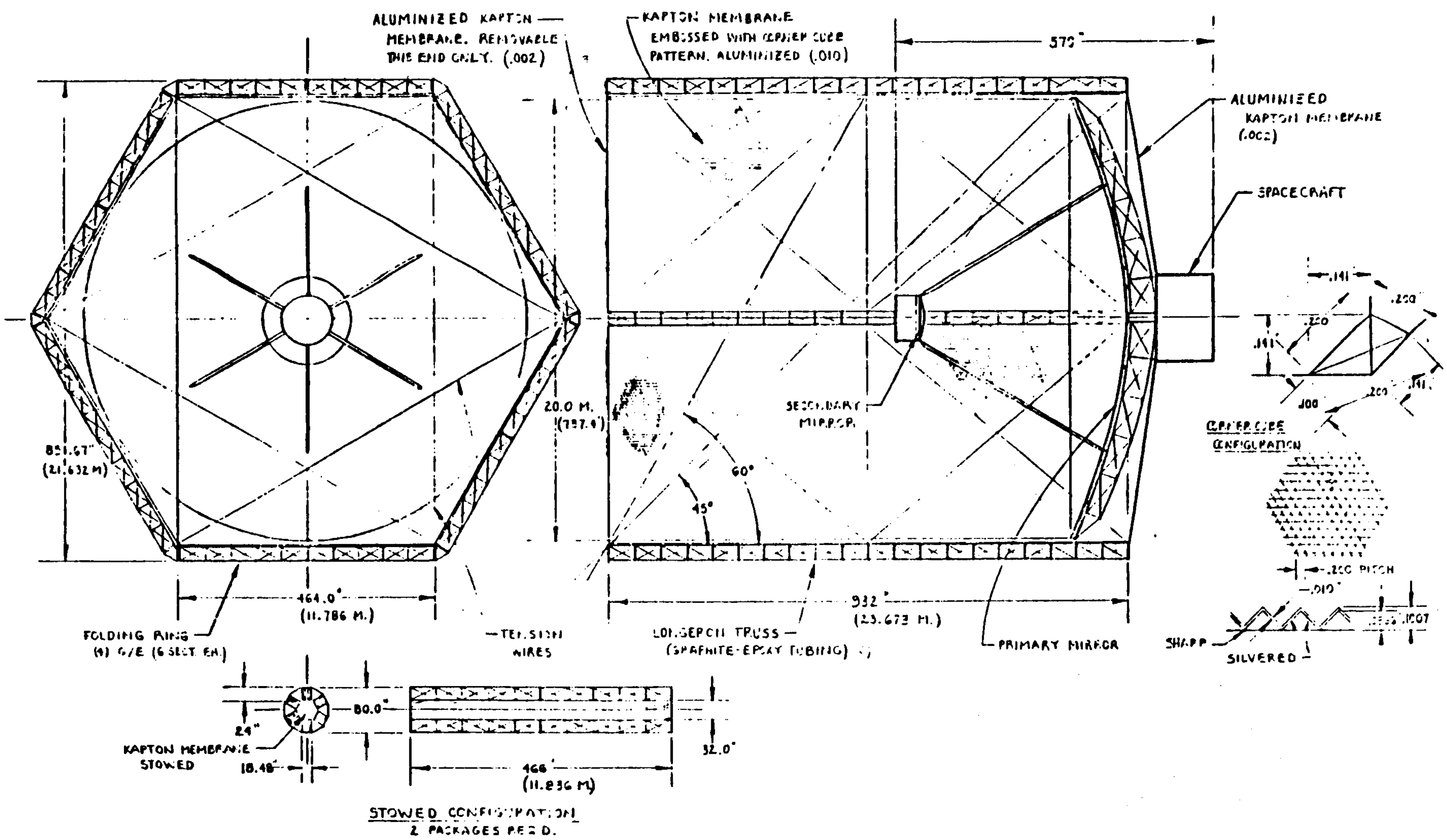
ALTERNATE SUNSHADE CONCEPT



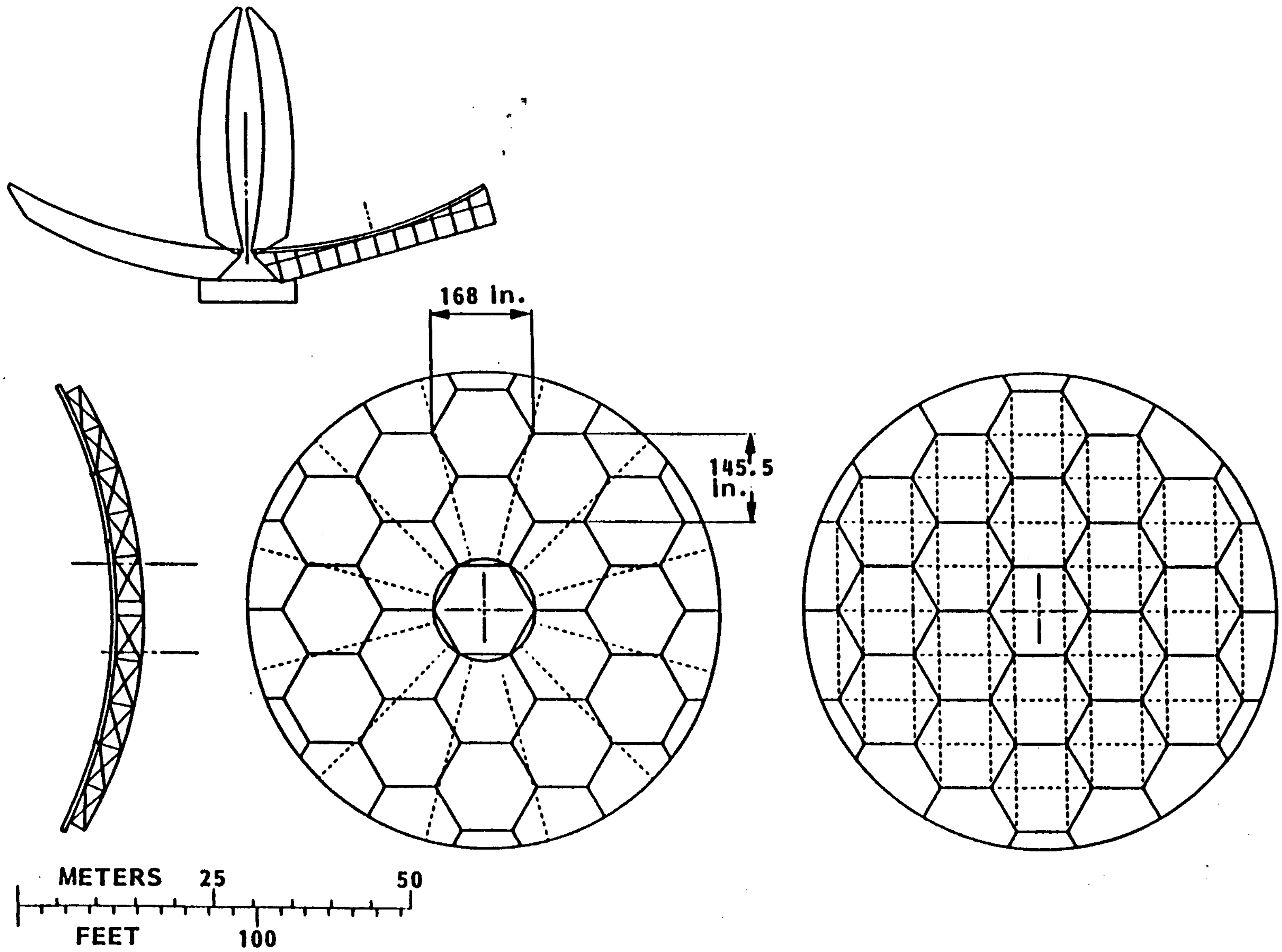
PRIMARY STRUCTURAL ARRANGEMENTS

Many structural arrangements are possible to adequately support the mirror segments. Two possible concepts are shown here; radial ribs and egg-crate geometry.

For this study radial ribs were selected since they represent a simple system for stoning in a small volume around a central hub. However alternative concepts should be evaluated with a view to determining a low cost/low weight design providing adequate stiffness and minimum EVA activity to achieve final assembly.

At the core of the design would be the location of standardized hardpoints located on the internally designed mirror segments that would provide direct load paths between the segments and basic truss elements.

PRIMARY STRUCTURAL ARRANGEMENTS



ORBITER CARGO CONFIGURATIONS

The major elements of LDR are shown here located in the cargo compartment of the shuttle.

The manifests for each load is summarized in these lists.

LDR Launch No. 1	LDR Launch No. 2
9 mirror elements	10 mirror elements
secondary optics	9 mirror elements (partials)
truss support hub	2 solar array assemblies
12 radial truss ribs	LDR spacecraft
robotic assembler	2 large comm. antennas
6 preassembled beams	Volume for unidentified LDR equipment
4 quivers of struts	

The first launch components would be stored on the space station until the second launch cargo has been delivered, thereafter the LDR and its support equipment would be assembled at the selected assembly site.

It should be noted that the entire LDR hardware inventory could be split up and delivered in several separate STS deliveries, provided adequate storage is provided for sensitive (mirror, cryogenics, etc) equipment.

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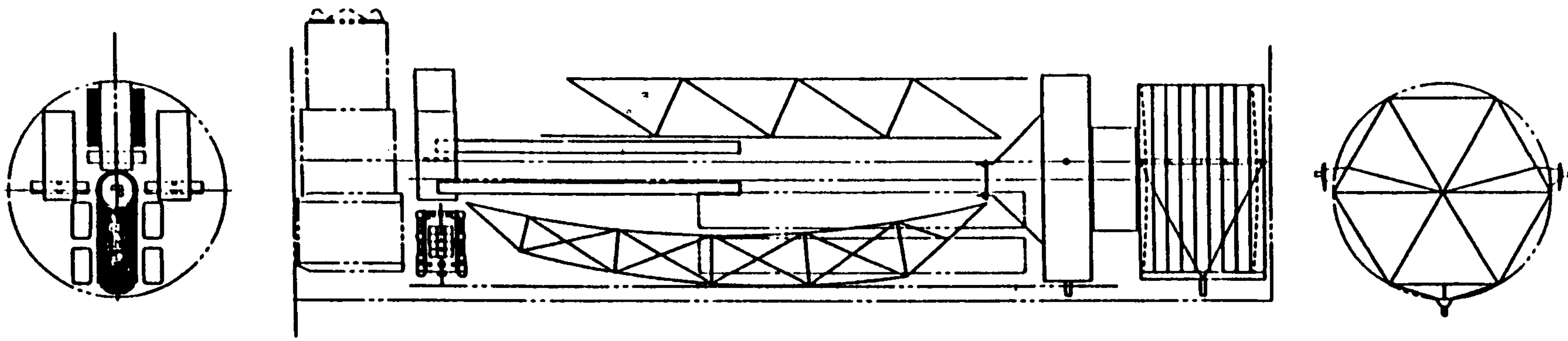
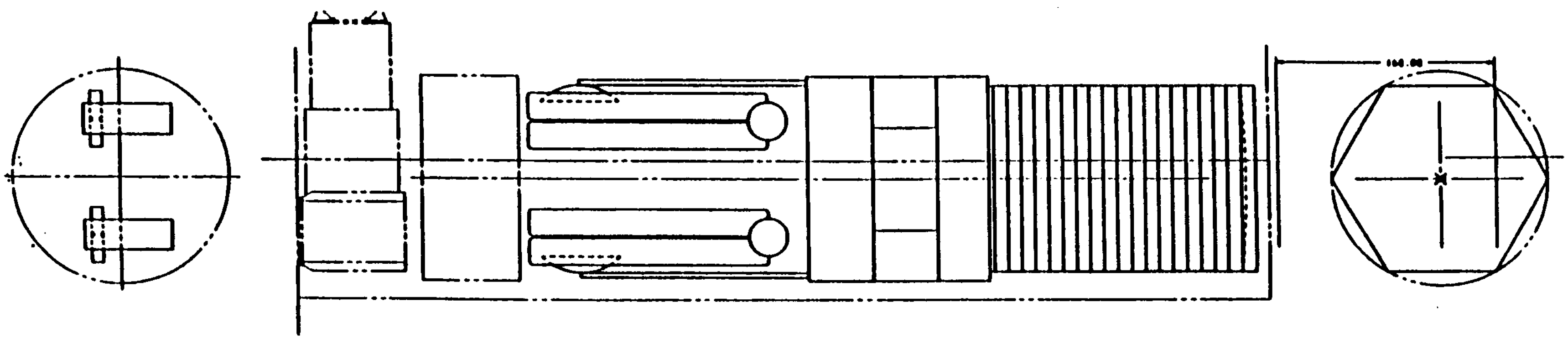
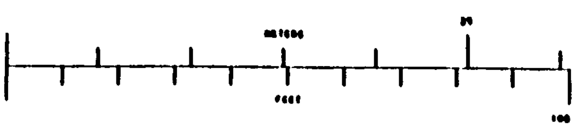
ORBITER CARGO CONFIGURATIONS



FIRST LAUNCH



SECOND LAUNCH



LDR ASSEMBLY APPROACH

This chart illustrates in simplified form a proposed technique for building the mirror primary support truss.

The stowed main ribs assembly is removed from the cargo bay and located on the turntable on the space station. (Note the ribs could be rotated to the configuration shown in section B-B while still in the shuttle cargo bay, provided all other equipment has been off-loaded).

The initial operation would be to rotate the ribs to their final radial location around the central hub and then locked in place; this would be a manual operation by two EVA crewmen.

The remainder of the assembly of the primary truss structure is shown on the next chart.

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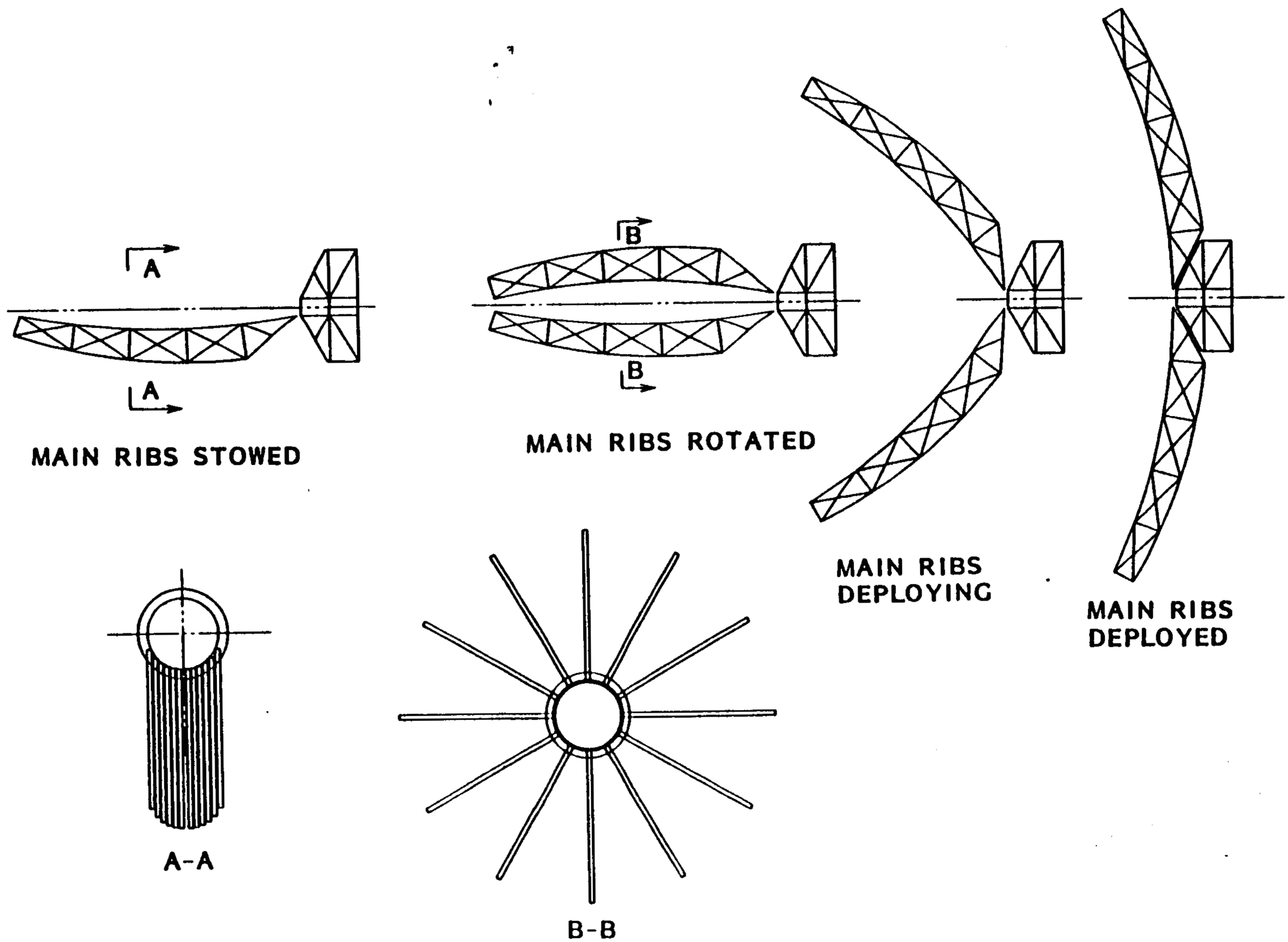
LDR ASSEMBLY APPROACH



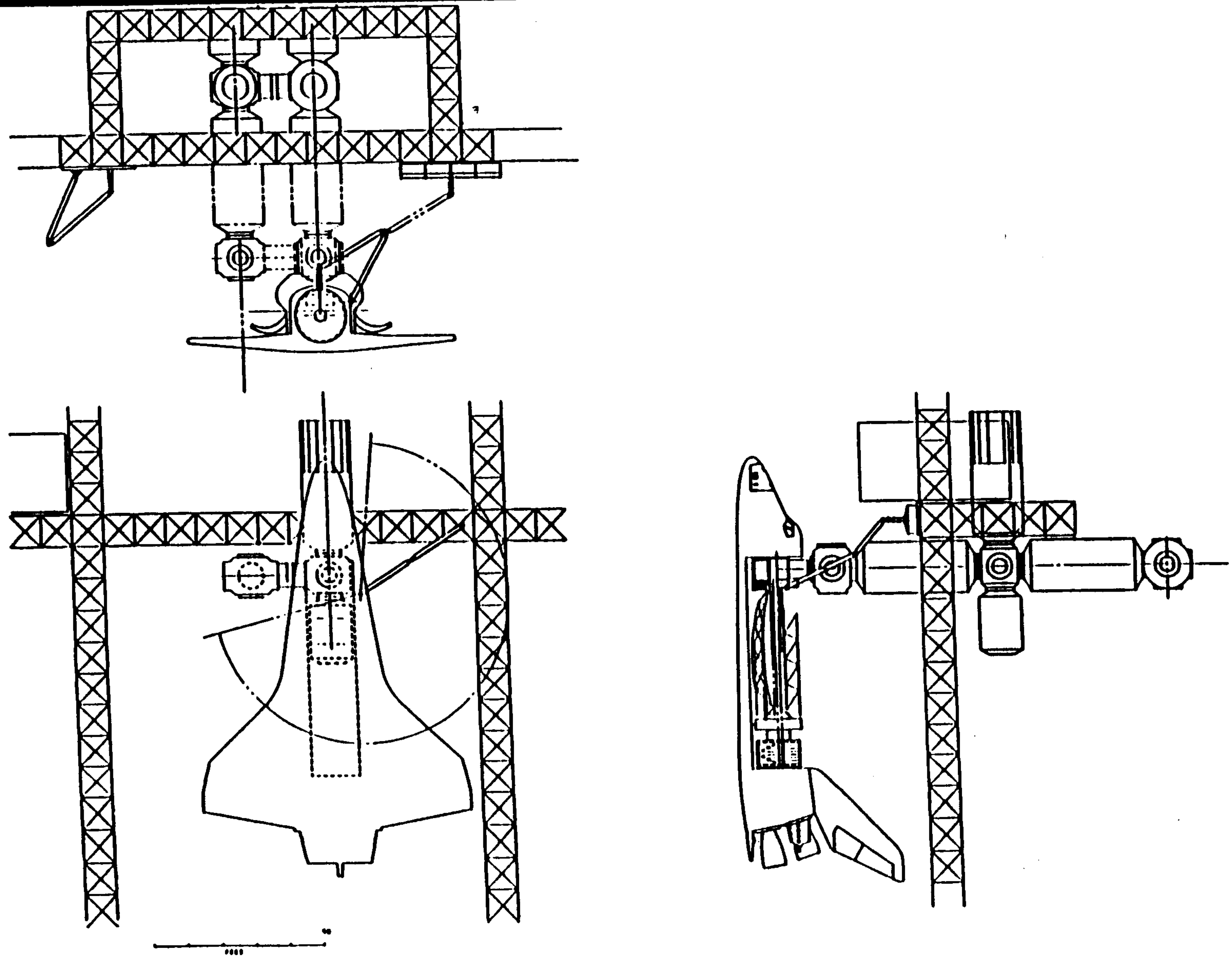
RMS UNLOADING CONSTRAINTS

The current space station configuration and orbiter docking location will provide direct access for the remote manipulator system to only approximately seven structural "cubes" on the forward face of the truss.

This would mean considerable MRMS activity to deliver LDR components to the LDR storage and assembly sites entailing much transfer of equipment between the RMS and the MRMS together with extensive EVA.

An alternative approach, which will save time and MRMS travel operations, is shown on the next chart.

RMS UNLOADING CONSTRAINTS



RMS TO MRMS HAND-OFF TECHNIQUE

This concept, which has been proposed by Astro-Aerospace (Canada) for general use on the space station, delivers cargo directly from the shuttle cargo bay to the MRMS on the station.

As can be seen in the sketch a considerable increase in delivery sites around the truss is possible; a versatility that would be time saving and requiring less EVA than required by using the RMS only.

For the system to work would require a minimum of two grapple fittings on each cargo compartment being delivered; which could be overcome perhaps by designing a standard space station cargo delivery pallet which would have a dual grapple fitting arrangement built-in.

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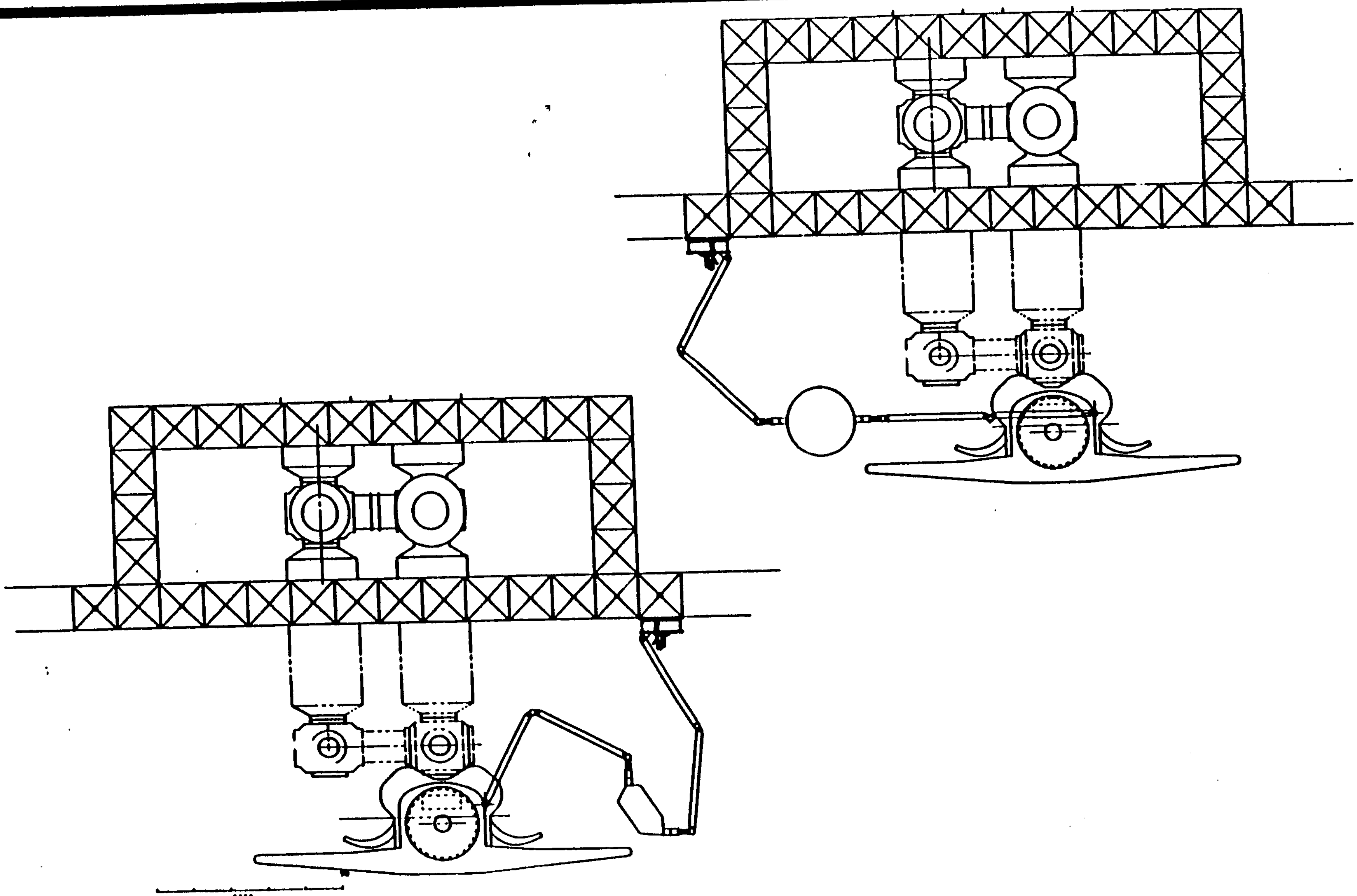
RMS TO MRMS HAND-OFF TECHNIQUE



LDR REFLECTOR ASSEMBLY APPROACH

This chart depicts the sequence of events required to erect the primary structure of the 20 meter truss which, when finally assembled, would have all of the hardpoints necessary to accept the mirror segment assemblies.

After deploying the 12 main ribs to their radial location a string of rim struts, attached at the outer edges of the main ribs, would stabilize the assembly early in the process simplifying subsequent strut assembly.

The outer face circumferential struts are next installed after which the inner face circumferentials and diagonals are added.

The concept requires the use of two EVA astronauts and utilises detail parts that are currently being developed for the primary truss on the space station.

Time lines have been developed for LDR and are included in later pages of this report.

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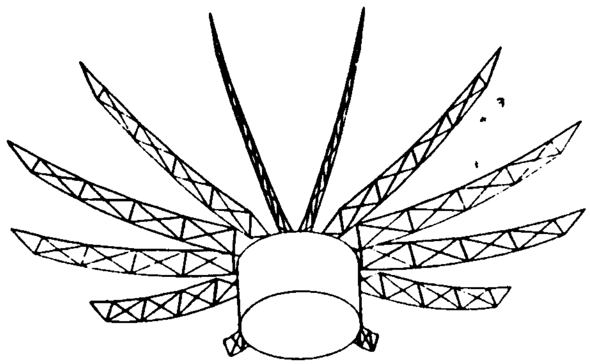
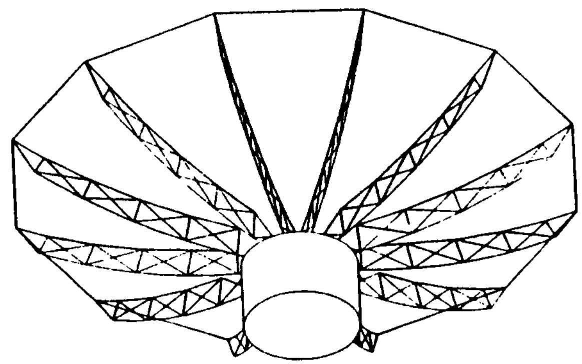
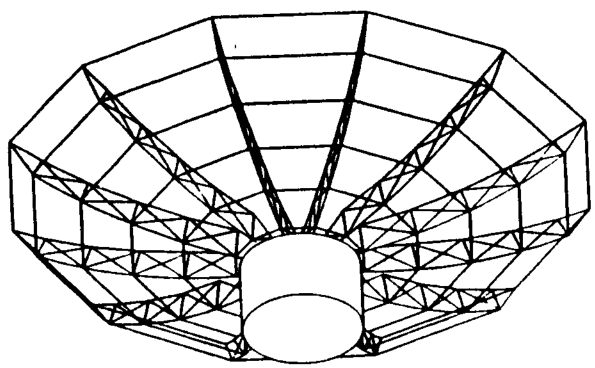
LDR REFLECTOR ASSEMBLY APPROACH



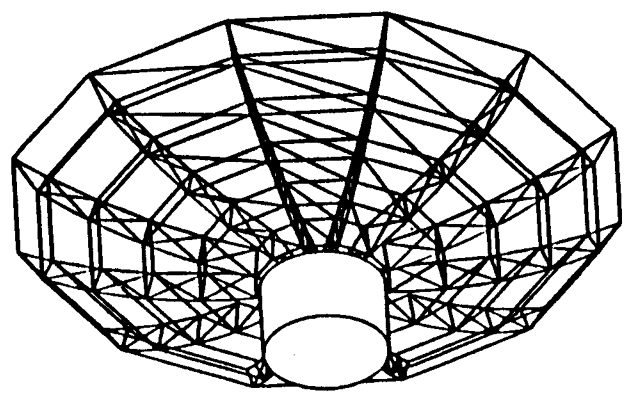
① DEPLOY 12 MAIN RIBS



② ATTACH OUTER RIM STRUTS



③ ATTACH OUTER FACE CIRCUMFERENTIAL STRUTS



④ ATTACH INNER FACE CIRCUMFERENTIAL STRUTS

SPACE STATION ASSEMBLY TECHNOLOGY

This design concept has been developed by Lockheed from an original design conceived at M.I.T.

The predominant feature is that is requires no rotation of the sleeve (a strenuous effort) to provide the locking feature at assembly.

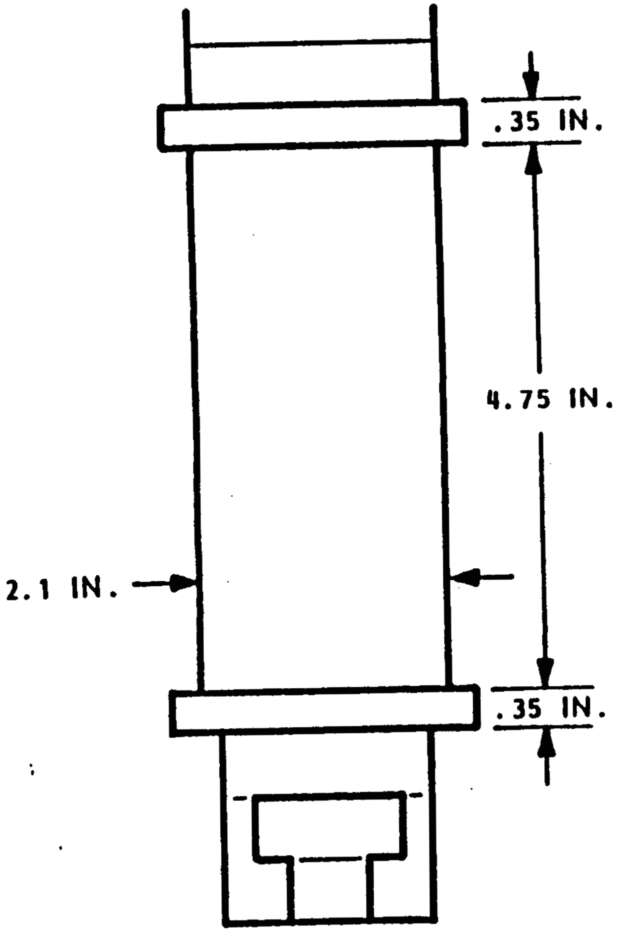
Also unique to this concept is the non-directional insertion, sideways, of the strut onto the node i.e. the mushroom boss will accept the strut from any (0° - 360°) direction normal to its longitudinal axis.

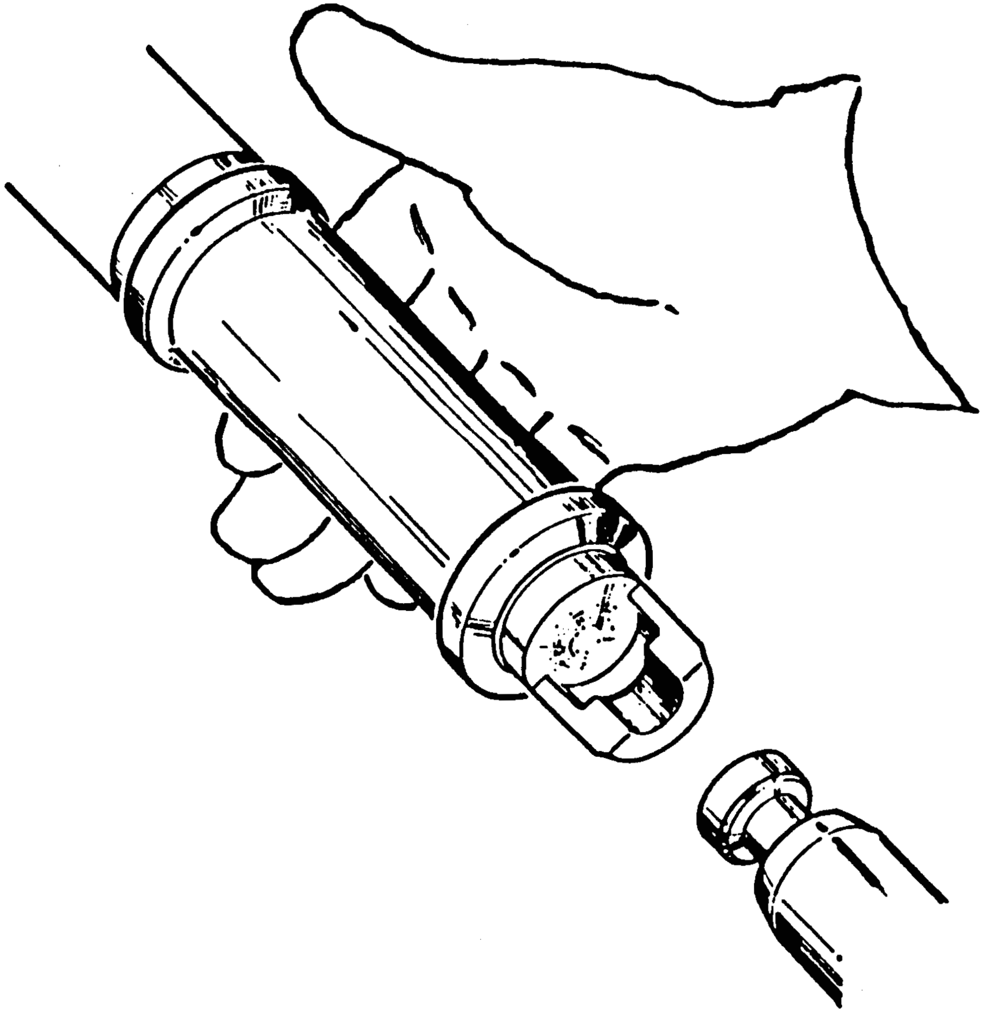
The astronaut, after locating the tube end fitting over the mushroom shaped boss on the node fitting, simply slides the external sleeve fitting over the boss until 17 bottoms out and automatically positively locks in place.

After considerable testing in a neutral bouyancy tank with suited astronauts it has been shown that the time to insert and secure each strut end requires between 5 and 18 seconds, depending on the truss geometry complexity.

The major time consuming operation is astronaut/equipment positioning and translating from one node location to another.

SPACE STATION ASSEMBLY TECHNOLOGY
GLOVE/STRUT INTERFACE





SIDEWAYS STRUT ASSEMBLY

The concept illustrated here is being developed at LaRC and utilizes tapering flanges in axial and radial planes to achieve a zero back-lash fit. Lockheed on the current design requires a twisting motion of the strut end fitting.

Node fittings are located on the boss to accept the strut end fittings and will be located such that there would be no interference in subsequent strut assemblies to the same boss.

Strut materials are graphite/epoxy with aluminum end fittings.

This and the previous chart are included here to demonstrate that there is considerable effort within NASA and industry to develope an erectable (with EVA) primary structure and this technology should be used in a cost effective manner on the LDR program.

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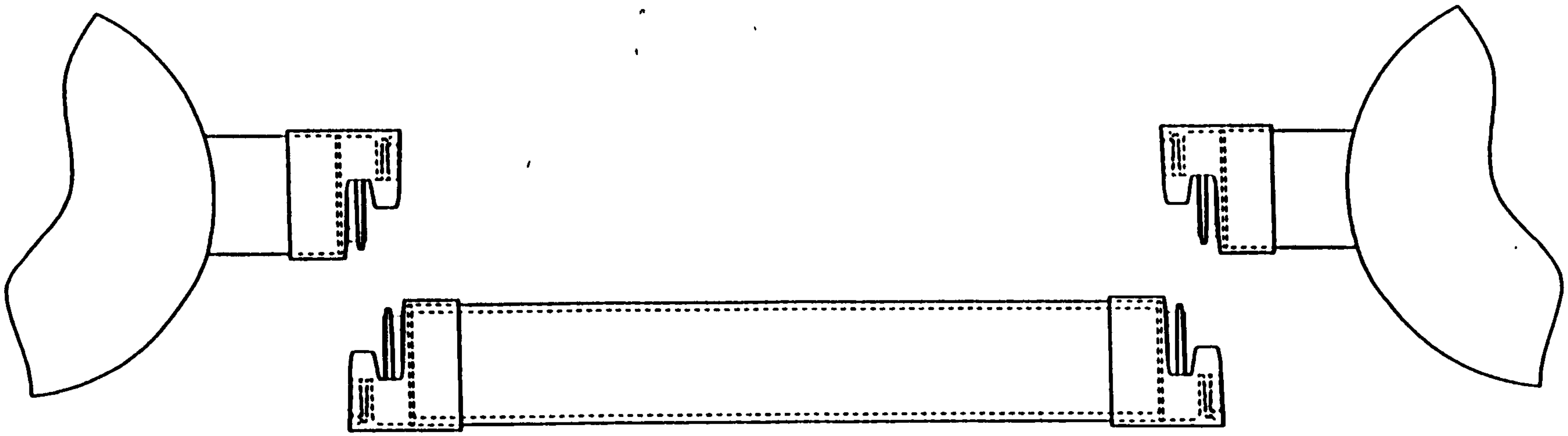
SIDEWAYS STRUT ASSEMBLY



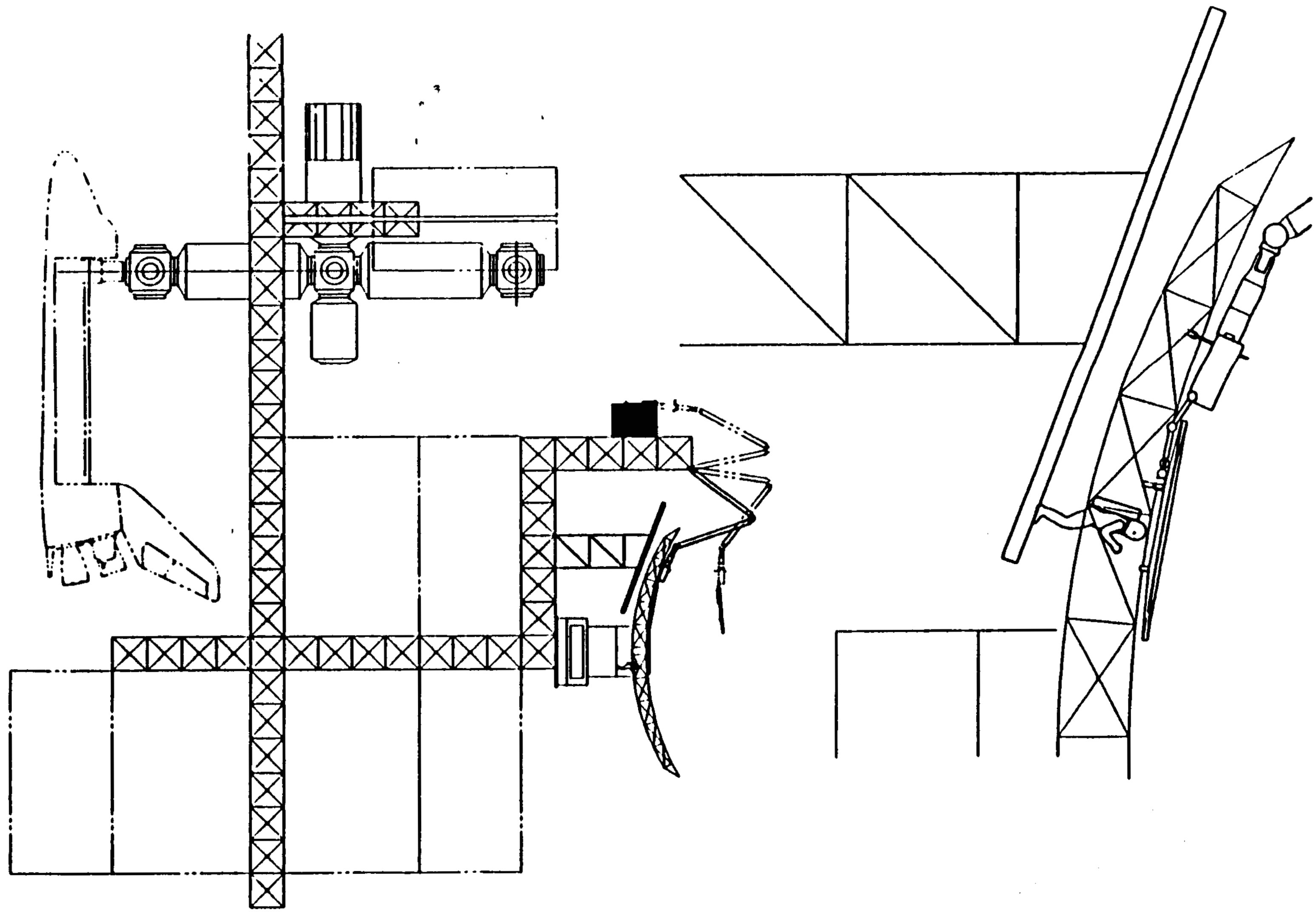
MIRROR ASSEMBLY

A robotic end effector for the MRMS is expected at the Space Station IOC. This robot itself is shown in greater detail in a subsequent illustration.

The lower illustration shows the MRMS attached to the specially constructed truss structure. From this position, the MRMS arm can reach both the reflector substructure and the mirror hex segment storage location.

The upper illustration gives a closer view of the robot attached to the MRMS arm. The robot has attached its two arms to the mirror segment, removed it from storage, and moved to the LDR structure. The movement of the MRMS is by teleoperation by an IVA crewmember. Vision incorporated in the robot assists the crewmember in finding the locating point on the structure. This point is a precisely defined part of the structural configuration and allows the robot to determine a precise position for subsequent robotic action. The MRMS lacks sufficient accuracy to perform robotically without this intermediate locating step. This point is grasped by the single extendable locating arm of the robot. Once attached the robot can execute preprogrammed subroutines in storage to locate and position the mirror segment over the actuators which are part of the LDR reflector substructure. These actuators incorporate servo clamps for precisely locating the segment. The robot can now release and withdraw its two arms and return for the next segment.

MIRROR ASSEMBLY



LDR DEPLOYMENT USING OMV

This sketch illustrates a possible concept for deployment of the LDR spacecraft from the space station.

After removal of the LDR dedicated support structural tower the MRMS is programmed to remove the orbital maneuvering vehicle (OMV) from its stowed location in the OMV hangar and secured to the LDR in the cavity at the turntable fixture on the end of the trusswork.

After checkout of all systems the LDR/OMV configuration is deployed by the MRMS; the OMV would use the low contamination low thrust for close proximity control prior to reaching a non contaminating distance before operating its main thrusters for the transfer-to-operational altitude for LDR.

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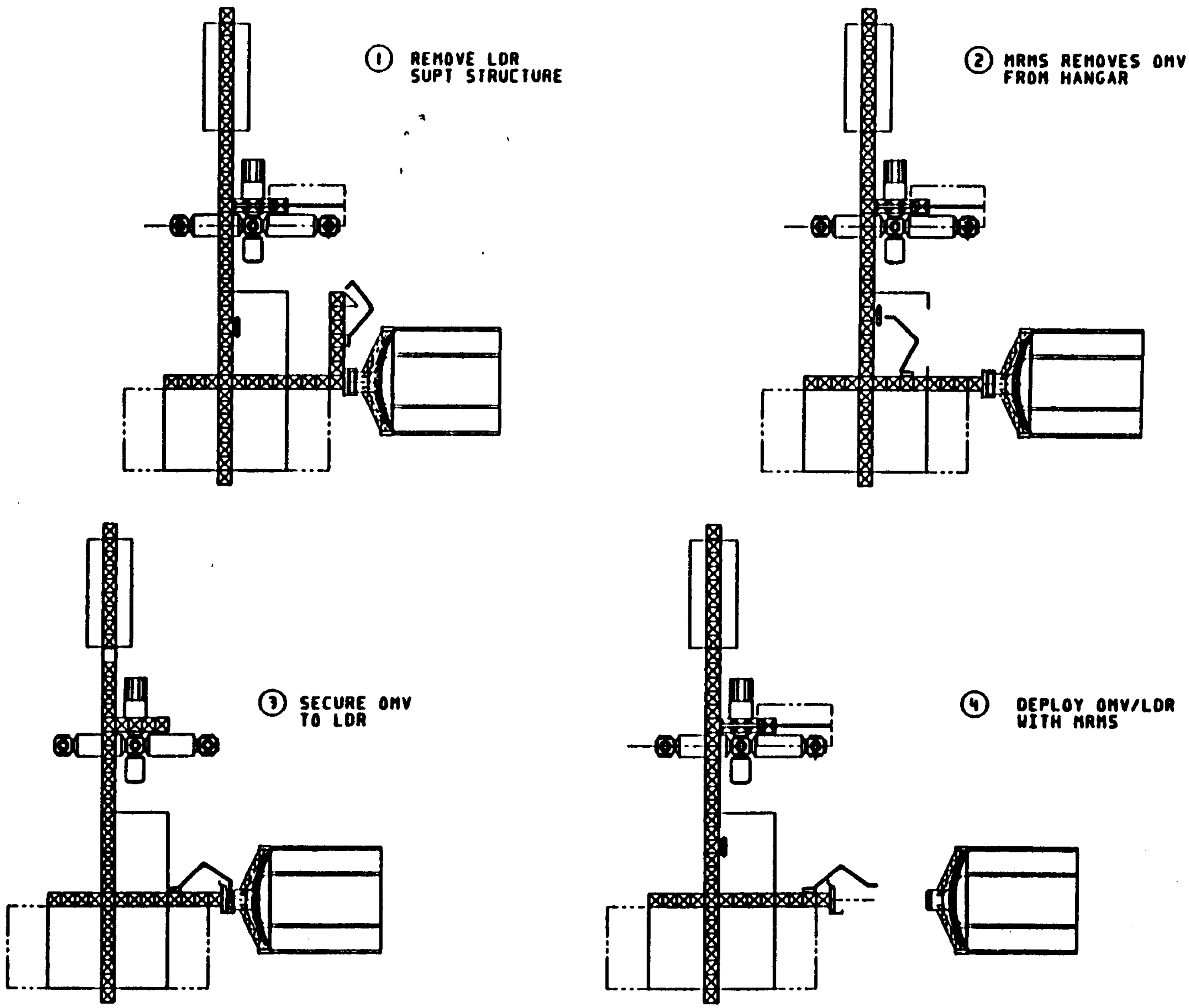
LDR DEPLOYMENT USING OMV



LDR - WEIGHT SUMMARY

A top level all-up weight estimate was made. The estimate includes replenishables (cryogen, propulsion) as well as structure to be placed on space station for assembly and checkout. The total weight implies a minimum of two shuttle trips to space station.

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LDR – WEIGHT SUMMARY *

ITEM		WEIGHT
SUNSHADE ASSY		3,400
MIRROR TRUSS		1,992
CIRCUM. STRUTS		751
REAR ASSY SUPPT. TRUSSES		346
MISC. SUPPTS		500
PRIMARY MIRROR ASSY		25,830
SECONDARY MIRROR ASSY		5,800
SOLAR ARRAY ASSY'S		1,480
ARRAYS	800	
BOOMS	170	
SUPPTS.	70	
GIMBALS	440	
**TURNTABLE		2,000
CONTROLS & ELECTRONICS		280
SSP ADD. TRUSS STRUCT **		1,800
SPACECRAFT		11,300
SCIENTIFIC INSTRS.		14,500
GROWTH (15%)		10,497
TOTAL LDR		80,476

*POUNDS
**DOES NOT FLY WITH LDR

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TECHNOLOGY AND LDR-UNIQUE

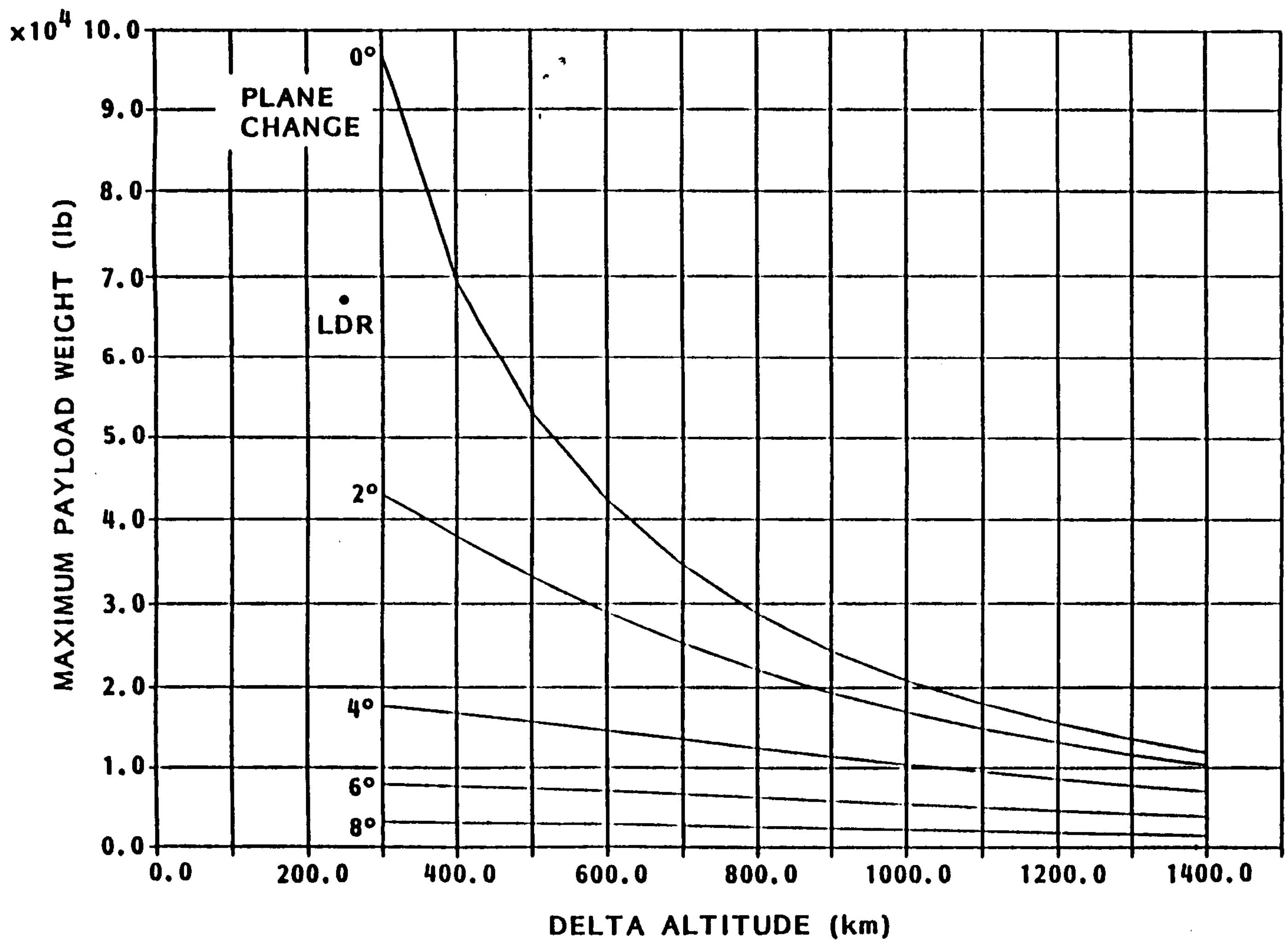
L. BANDERMANN

T. DOLTON

OMV PLANE CHANGE CAPABILITY FOR PAYLOAD RETRIEVAL

The maximum payload weight which the OMV can retrieve from the payload operating orbit to the space station, is shown as a function of the altitude difference between the two orbits and for various differences in orbital inclination at time of retrieval. Because they are at different altitudes, the two orbits precess at different rates and, even though they are coplanar at regular intervals (about once a year for a 2500 km altitude difference), they become inclined relative to each other. The maximum inclination between the orbits is equal to 28.5° presuming both orbits to be initally in a 28.5° circular orbit. If the LDR orbit is maintained at $\approx$750 km, $\approx$250 km above the space station, then, for a typical LDR weight of 65,000 lb, the OMV can manage only a $\approx$1° plane change. For lower LDR altitudes, the inclination can be somewhat larger, and for higher altitude it must be smaller. The next chart gives the impact of these limitations on the time available for OMV retrieval of LDR to space station.

OMV PLANE CHANGE CAPABILITY FOR PAYLOAD RETRIEVAL



<u>OMV SERVICE WINDOW</u>

For a 1° orbit plane change during LDR retrieval to space station, the time for the OMV to go up to LDR and retrieve it to the station is about 5 days. If the OMV could manage a larger inclination change (or a different retrieval vehicle were available), then, for the same LDR orbit altitude, the time available for LDR retrieval could be larger.

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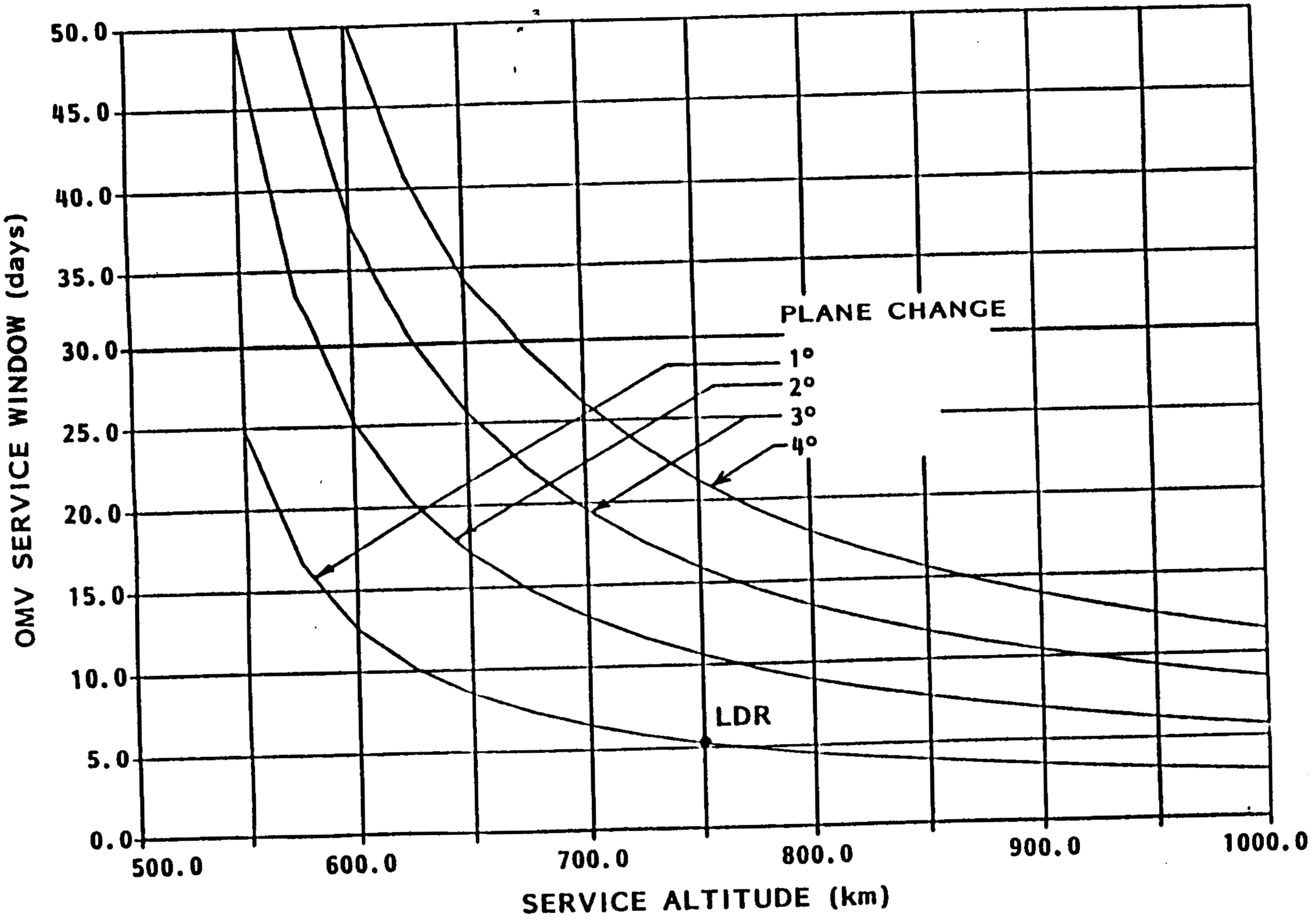
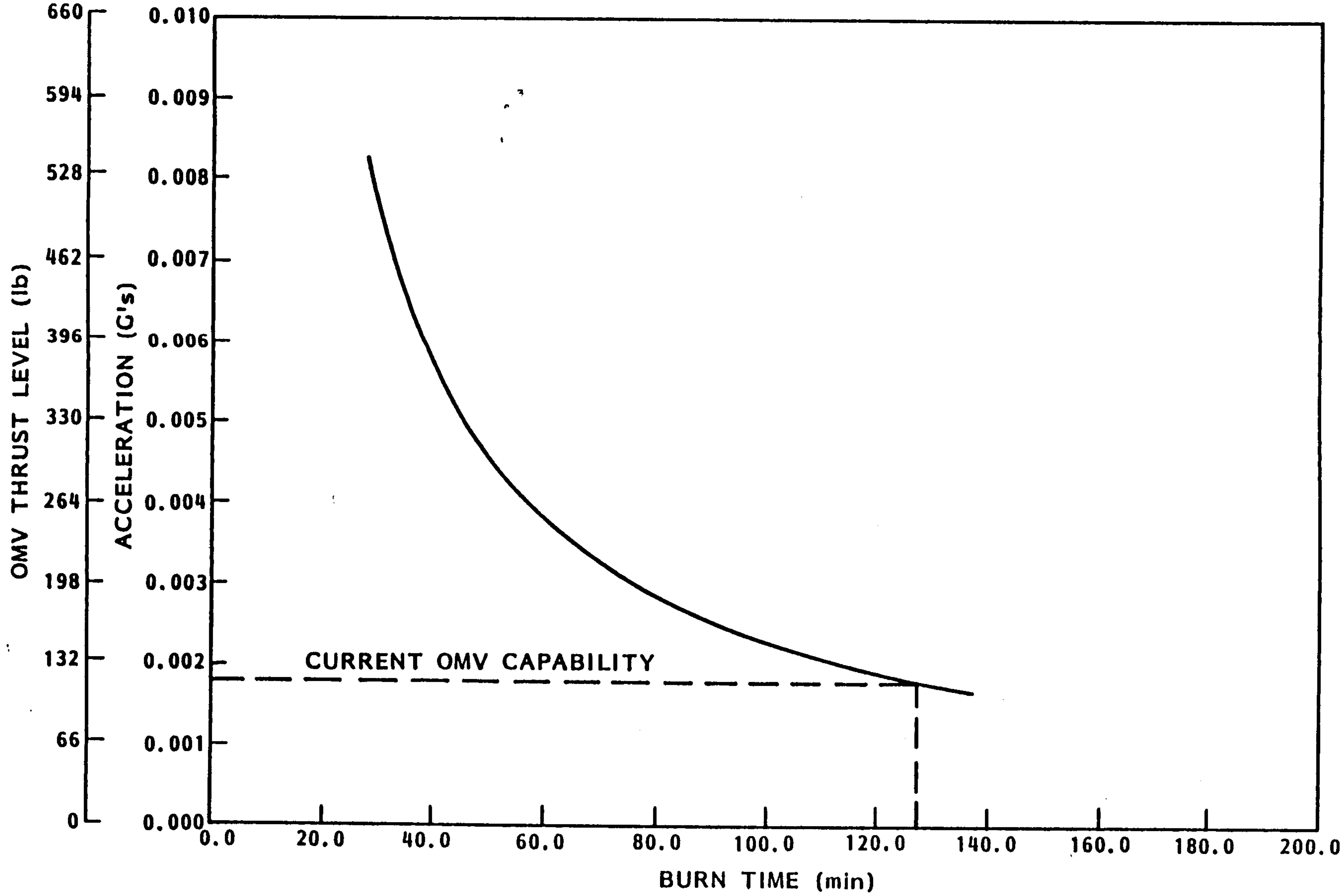
OMV SERVICE WINDOW



LDR ACCELERATION - OMV THRUST LEVEL

This chart shows the required continuous thrust of the orbit transfer vehicle as a function of burn time. For the currently baselined OMV thrust capability, the burn time to transfer LDR to the station would be approximately 2 hours and the acceleration involved is slightly less than 0.002 g's. The tolerable maximum acceleration of LDR is not yet known, but one may take the value for Space Telescope, 0.01 g, as representative. Then, because of the limited thrust level of OMV, the expected maximum acceleration of LDR during orbit transfer is small.

LDR ACCELERATION – OMV THRUST LEVEL



INCREASED SPACE STATION DRAG

With LDR on space station, the cross sectional area of the station increases by almost 30%, whereas the mass increases by less than 10%. The resulting decrease in mass/area ratio implies a higher orbit decay rate for space station with LDR aboard - albeit only 15% higher. Since at the presumed altitude of space station - 500 km - the station is more or less under continuous power to make up for the air drag, this power level could be increased during LDR deployment. As an alternative - involving less contamination of LDR and other payloads on the station - would be to start assembly with the station at a high orbit altitude, let the space station orbit decay during assembly, and reboost after LDR has left the station.

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INCREASED SPACE STATION DRAG

- ESTIMATED MASS, AREA, AND M/A RATIO

	MASS (10^3 kg)	AREA (10^3 m^2)	M/A (kg/m^2)
STATION WITHOUT LDR WITH P/Ls	307	2.24	137
LDR	30	0.63	48
STATION WITH LDR + P/L's	337	2.87	117

15% DECREASE

- ACTION DEPENDS ON RESIDENCE TIME OF LDR ON STATION
  - INCREASE ORBIT BOOST
  - START LDR ASSEMBLY AT HIGH POINT, LET DECAY; REBOOST AFTER LDR DEPLOYED FROM STATION

IMPACT OF LDR ON SPACE STATION'S ATTITUDE CONTROL SYSTEM (ACS)

A first look was taken at what impact attaching the LDR to the Space Station would have on the stability of the Station's attitude control system (ACS). The steps taken in this brief study were the following. First, an ACS was designed for the Station without the LDR attached. The new reference configuration, the dual keel design, was used for the study. However, the initial operating configuration (IOC) with a representative payload set on the upper and lower booms had to be used rather than the growth version at the time LDR would be attached as these were the only data available at the time of the study. Because the growth Station will be more massive than the IOC Station, the results should be conservative, as the LDR represents a greater percentage of the total mass at IOC.

A mathematical model of 3-degree-of-freedom attitude equations was constructed from the estimated mass properties. Gravity-gradient forces were included in the model. Aerodynamic drag was not; however, this is expected to have minor effect on the attitude because, unlide the old power-tower configuration, the center of pressure is very near the center of mass.

Based on this mathematical model, a low-bandwidth controller was designed. The lowest structural frequency of the dual-keel Station is about 0.1 Hz (depending primarily on the assumed lowest bending frequency of the solar arrays). In order to avoid interaction between the ACS and the structure, the ACS bandwidth was chosen well below this at 0.003 Hz.

The next step in the study was to determine the attitudinal stability with the LDR attached to the Station while keeping the same control gains. Two different locations for attaching the LDR were considered.

IMPACT OF LDR ON SPACE STATION'S ATTITUDE CONTROL SYSTEM (ACS)

STEPS IN STUDY:

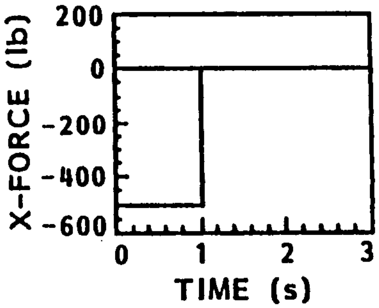
- DESIGN CONTROL SYSTEM FOR SPACE STATION WITHOUT LDR
  - REFERENCE DUAL REEL DESIGN AT INITIAL OPERATING CONFIGURATION (ONLY DATA AVAILABLE AT TIME OF STUDY)
  - REPRESENTATIVE PAYLOAD SETS ON UPPER AND LOWER BOOMS
  - GRAVITY GRADIENT FORCES WERE INCLUDED IN MODEL
  - LOW BANDWIDTH (0.003-Hz) DESIGN TO AVOID INTERACTION WITH STRUCTURAL MODES (ABOUT 0.1 Hz AND ABOVE)
- INVESTIGATE IMPACT ON ATTITUDE STABILITY WITH LDR ATTACHED
  - USE SAME CONTROL GAINS FROM DESIGN ABOVE
  - CONSIDER TWO LOCATIONS FOR ATTACHING LDR TO STATION

RESPONSE FROM FAILED-DOCKING OF SHUTTLE IS SIMILAR WITH AND WITHOUT LDR

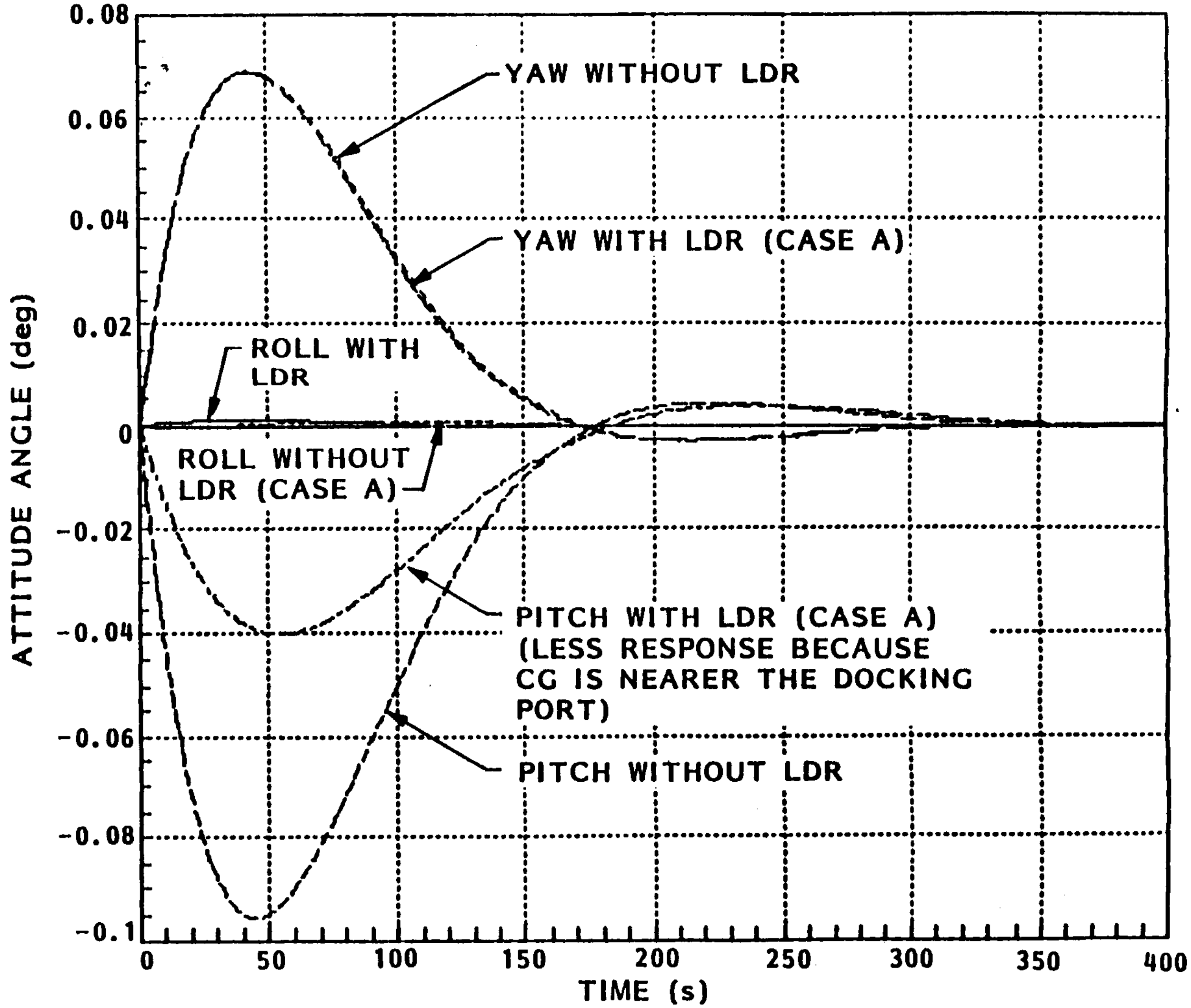
One of the most severe forces to be encountered by the Station in normal operations is that due to a failed docking of the Shuttle Orbiter. NASA's reference for this force is a square wave having an amplitude of 500 pounds and a duration of one second. Its sense is into the docking port, which for the reference dual-keel configuration is in the negative x direction.

The simulation response of the mathematical model of the ACS to this force was computed for two cases. The first case was with the LDR not attached; the second was with the LDR attached on the lower boom between the two keels (Case A in the previous figure). As can be seen in this figure, the general behavior of the responses is the same. The roll and yaw responses are virtually identical. (Very little roll response occurs because the force is parallel to the roll axis; the roll response which does occur results from roll-yaw coupling.) The pitch response with the LDR attached has a lower amplitude because the presence of the LDR brings the centerof mass of the Station closer to the docking port, meaning the moment arm is less. However, the key result is that the motion is stable in both cases and damps out in roughly the same amount of time.

RESPONSE FROM BERTHING OF SHUTTLE IS SIMILAR WITH AND WITHOUT LDR



THIS EXCITATION FROM BERTHING OF THE SHUTTLE ORBITER CAUSES THIS ATTITUDE RESPONSE

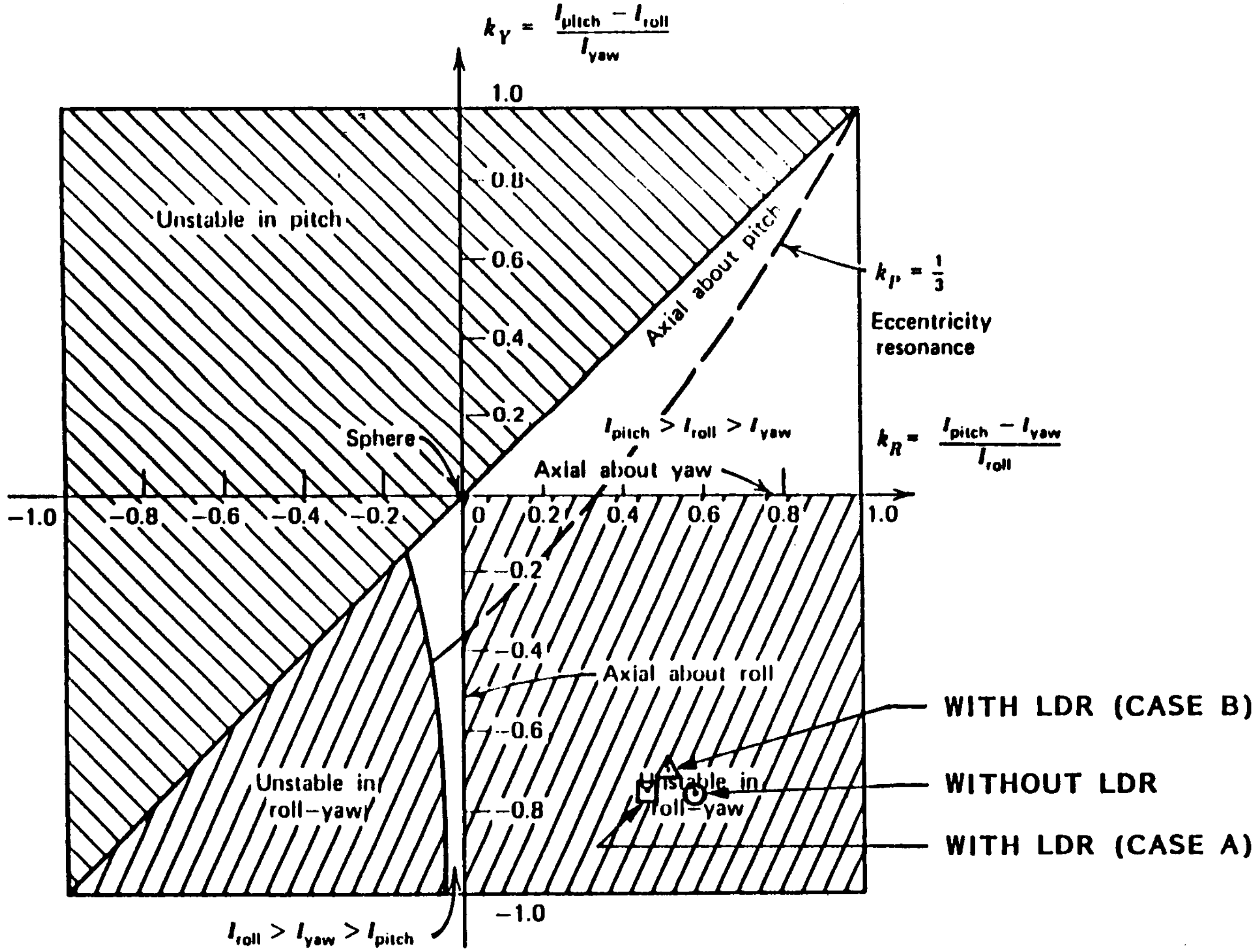


LDR DOES NOT CHANGE GRAVITY GRADIENT INSTABILITY

The dual-keel configuration is not inherently stable in its normal attitude of flight. The gravity-gradient torques will cause it to roll and yaw 90 degrees to a stable flight attitude if not controlled by the ACS. This property is a function of the principal moments of inertia of the Station, as indicated in this figure. The cross-hatched areas indicate regions of inherent gravity-gradient instability. The upper-left cross-hatched area is a region unstable in pitch. The other cross-hatched areas are regions unstable in roll and yaw.

Three points are plotted in the figure corresponding to three cases: Case A and Case B, for which the LDR is attached to the Station in different locations, and the case with LDR not attached to the Station. All three points lie in the region of roll-yaw instability, and the closeness of the three points indicate that the behavior is little affected by the presence of the LDR.

LDR DOES NOT CHANGE GRAVITY GRADIENT INSTABILITY



- GRAVITY GRADIENT STABILITY REGIONS ARE FUNCTION OF PRINCIPAL MOMENTS OF INERTIA

CLOSED-LOOP POLES OF ACS

Two different orientations of LDR relative to the station were studied, as illustrated in this chart. In either case, the location of the poles of the solutions of the dynamical equations are little affected by presence of LDR on the station.

CLOSED-LOOP POLES OF ACS MOVE VERY LITTLE WITH LDR ATTACHED

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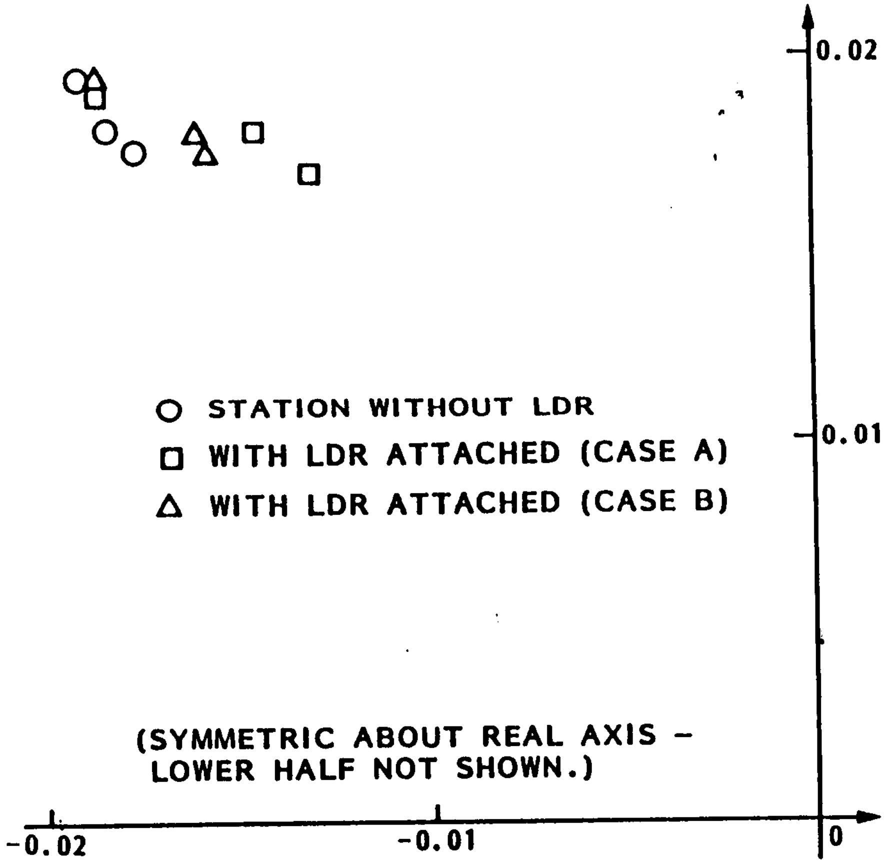
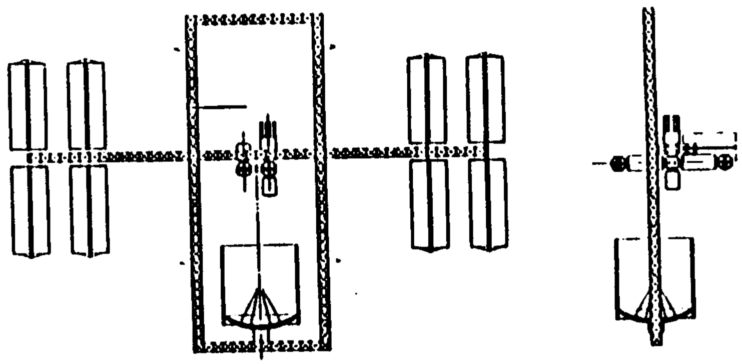
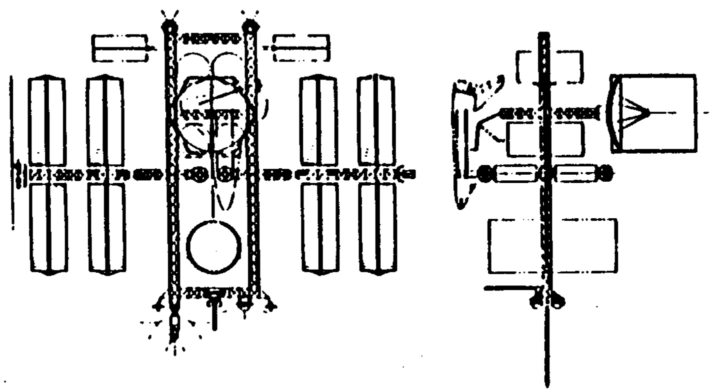


RIGID-BODY CLOSED-LOOP POLES

CASE A



CASE B



LDR/SS/STS INTERFACE CONTAMINATION SOURCES

Three major contamination events on space station are shown: Firing of the station's RCS, water dump and gas releases, and orbiter operations near the station. OMV will have a cold gas engine for operation near contamination sensitive locales; it is therefore not shown here as another major contaminant.

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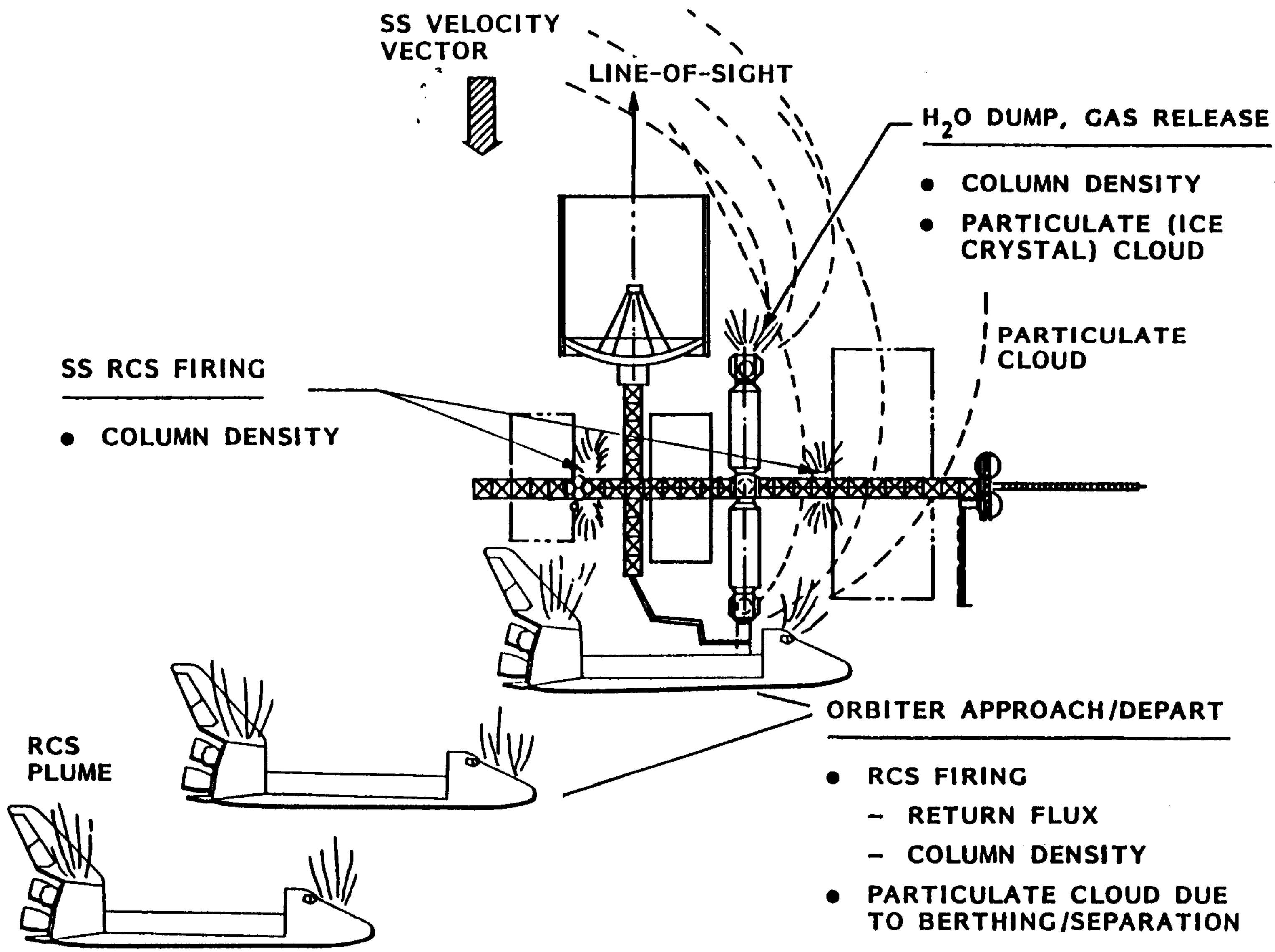
LDR/SS/STS INTERFACE CONTAMINATION SOURCES



LDR/SS/STS INTERFACE CONTAMINATION PREDICTIONS

The contamination of the SS near-environment is quantified for the three major contamination events illustrated earlier: the columnn densities of contaminant molecules and the solid particles in the line of sight are shown as a function of time for several event durations (10,100 and 1000 sec). As can be seen, initially there is a rapid decrease of contaminant concentrations, but after a few days the decrease proceeds much more slowly. Consequently, the acceptable level of these various contaminants for LDR must be compatible with the near-terminal concentrations shown here, or else special precautions must be taken to isolate LDR from the contaminants, e.g. using a contamination-free hangar.

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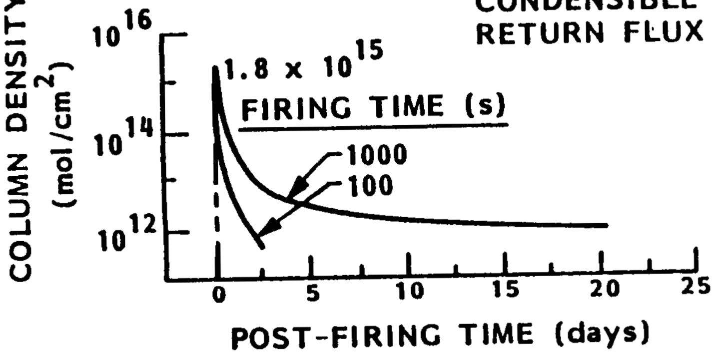
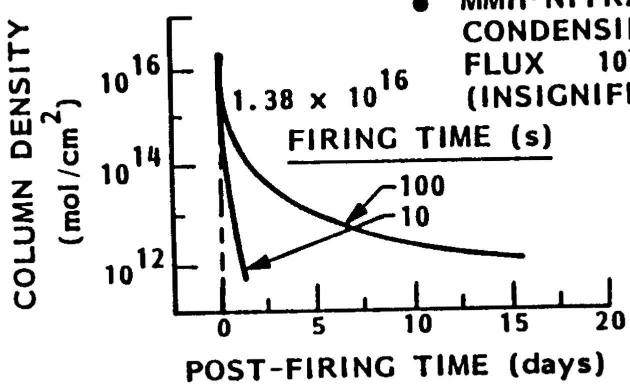
LDR/SS/STS INTERFACE CONTAMINATION PREDICTIONS

SS RCS FIRING



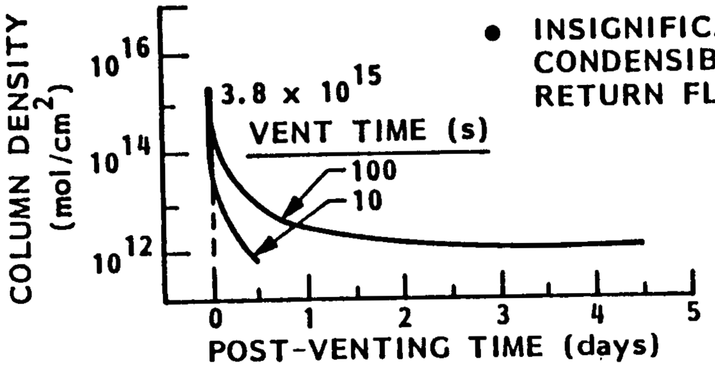
- INSIGNIFICANT CONDENSIBLE RETURN FLUX

ORBITER RCS (F3U, L2U, R2U) FIRING



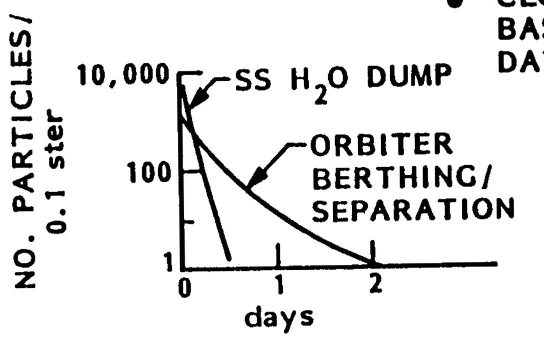
- MMH-NITRATE CONDENSIBLE RETURN FLUX 10^{-10} g/cm^2-s (INSIGNIFICANT)

SS H_2O VAPOR VENTING



- INSIGNIFICANT CONDENSIBLE RETURN FLUX

PARTICULATE CLOUD DISPERSION



- CLOUD DECAY BASED ON STS-4 DATA

CONTAMINATION: EFFECTS

This chart addresses the possible effects of particulate surface contaminants (dust) on LDR performance. A contamination level of MIL-STD 300 is assumed: i.e. in the particle distribution there is at most one particle of diameter 300 μm per sq. ft. of surface area. Optical effects include thermal emission of the dust and scattering of sunlight (at large angles) or from bright sources in the field-of-view (small angle scattering). Thermal emission is the dominant effect and comparable to the thermal emission by the LDR primary mirror. A Class 300 surface cleanliness level may be difficult to achieve and special post-deployment cleaning of the mirror may be required.

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CONTAMINATION: EFFECTS

- SURFACE PARTICULATES
  - MIL-STD 1246A CLASS 300 ASSUMED
- STRAYLIGHT/BACKGROUND
  - THERMAL EMISSION
  - SCATTERING
    - -- OF BRIGHT OBJECT IN FOV
    - -- OF SUNLIGHT
- CONCLUSIONS
  - THERMAL EMISSION DOMINANT
  - CLASS 300 STANDARD MAYBE DIFFICULT TO ACHIEVE
  - IF SO, EMISSION COMPARABLE TO MIRROR

THERMAL IMPACT OF LDR ON SS: HEAT FLUX VARIATIONS (2 Charts)

The impact of LDR on the heat fluxes on four subsystems of the space station was calculated: the solar panels, the servicing bay, the habitation and laboratory modules, and the thermal radiators of the station. The impact was calculated for two β angles (angles of sun from space station orbital plane): 0° and 52°. The thermal impact of LDR on these subsystems is small, and is greatest for the HAB/LAB modules where the flux increases, about 10%.

THERMAL IMPACT OF LDR ON SPACE STATION HEAT FLUX VARIATION

$\beta = 0^\circ$

	Q* $\left(\frac{Btu}{h}\right)$ W/O LDR	Q* $\left(\frac{Btu}{h}\right)$ W/LDR	+ Δ%
SOLAR ARRAY PANEL FRONT/BACK	$2.56 \times 10^5 / 1.45 \times 10^4$	$2.56 \times 10^5 / 1.45 \times 10^5$	0%/0%
SERVICING BAY	5.98×10^5	5.92×10^5	-0.67%
HAB MODULE	6.41×10^4	5.68×10^4	-11.4%
LAB MODULE	6.41×10^4	5.68×10^4	-11.4%
RADIATOR PANEL TOP/BOTTOM	$3.56 \times 10^4 / 8.12 \times 10^3$	$3.23 \times 10^4 / 8.11 \times 10^3$	-9.27%/-0.12%

*Q INCLUDES ORBITAL AVERAGED SOLAR, ALBEDO, AND PLANETARY FLUX AS WELL AS DIFFUSE REFLECTIONS

THERMAL IMPACT OF LDR ON SPACE STATION HEAT FLUX VARIATION $\beta = 52^{\circ}$

	$Q^{*} \left(\frac{Btu}{h}\right)$ W/O LDR	$Q^{*} \left(\frac{Btu}{h}\right)$ W/LDR	+ Δ%
SOLAR ARRAY PANEL FRONT/BACK	$1.94 \times 10^{5}/1.13 \times 10^{5}$	$1.94 \times 10^{5}/1.14 \times 10^{5}$	0%/0.89%
SERVICING BAY	7.13×10^{5}	7.11×10^{5}	-0.32%
HAB MODULE	6.03×10^{4}	5.34×10^{4}	-11.5%
LAB MODULE	6.03×10^{4}	5.34×10^{4}	-11.5%
RADIATOR PANEL TOP/BOTTOM	$3.30 \times 10^{4}/4.99 \times 10^{3}$	$3.19 \times 10^{4}/4.98 \times 10^{3}$	-3.3%/-0.2%

$$+ \Delta\% = \frac{Q_N - Q_{W/O}}{Q\ W/O} \ X/\infty$$

*Q INCLUDES ORBIT AVERAGED SOLAR, ALBEDO, AND PLANETARY FLUX AS WELL AS DIFFUSE REFLECTIONS

PAYLOADS REQUIRING SERVICING AT STATION

There are other payloads requiring the unique servicing needs which LDR requires. In particular is cryogen transfer. The SIRTF requires liquid helium transfer as does LDR. This is a new technology for space flight, and SIRTF will have "pioneered" the process before LDR, per the current schedules.

SIRTF will first be filled with cryogens in space during its first servicing mission, which is scheduled in 1994. LDR will first use this transfer technology in 1997, in its assembly process.

SIRTF may be located at the servicing bay which will be near the upper boom of the station; cryogens will be transferred there. LDR will be located in the Large Structures Assembly Area at the lower boom. Hence, LDR may be the first payload to have this process applied at this station location.

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PAYLOADS REQUIRING SERVICING AT STATION

- LDR ASSEMBLY OCCURS IN SAME YEAR AS OTV HANGAR ASSEMBLY:
  5 YEARS AFTER IOC: 1997
- SIRTF (RELEVANT TO LDR DUE TO CRYOGEN TRANSFER NEEDS) BEGINS OPERATION BEFORE LDR: 1994 VS 1997
- SIRTF IS SERVICED MORE FREQUENTLY THAN LDR:
  1 & 1/2 VS 2 YEARS
- LDR WILL RECEIVE CRYOGENS AT ASSEMBLY SITE; UNLIKE SIRTF WHICH IS IN SERVICING BAY

CONCLUSIONS:

1. LDR NOT FIRST PAYLOAD TO UTILIZE CRYOGEN TRANSFER PROCESS
2. LDR MAY BE FIRST PAYLOAD TO HAVE CRYOGENS LOADED AT ASSEMBLY PORT

SPACE STATION PAYLOADS REQUIRING SERVICING AT STATION:

CONSUMABLES REPLENISHMENT

The Mission Requirements Data Base indicates desired servicing schedules of Space Station customers. Those for consumables replenishment are shown in the chart for the ten year growth period.

The LDR assembly and servicing events are indicated, and their occurrence relative to other customers is seen. SIRTF's schedule is the other payload which is most noteworthy, since it also will be resupplied with liquid helium. Its servicing begins prior to LDR and occurs more frequently: 1 and 1/2 vs every 2 years.

SPACE STATION PAYLOADS REQUIRING SERVICING AT STATION: CONSUMABLES REPLENISHMENT

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NEW YR	PAYLOAD NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	
	YEAR AND QUARTER	1				2				3				4				5				6				7				8				9				10				
1	L-003	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	L-004	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	LIF-311	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	MAT 130	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	M002	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SAAX0013					1																																				
	SAAX0017												1												1												1					
	SAAX0022	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SAAX0026											1												1											1							
	SAAX0027											1												1											1							
	TDMX2011	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
2	SAAX0004 ← SIRTF														1						1						1						1						1			
	SAAX0023						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SAAX0028																			1											1											
3	COMM4000													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	S002														1								1																			
	SAAX0024													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SAAX0029																							1											1							
	SAAX0404									3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	TDMX2542											1		1						1		1						1		1						1		1				
4	LIF312													3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	M003													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SAAX0025													1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
	SPA801																			1						1						1						1				
5	S001																		1		1		1		1		1		1		1		1		1		1		1		1	
6	SAAX0020 ← LDR																													1								1				
7	S010																										1															
	SAAX0402																									3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
	SAAX0501																																		1							
	SAAX0504																																		1							
8	SAAX0221																																					1				1
	SAAX0222																																					1				1
	SAAX0223																																					1				1
	SAAX0228																																									1

ASSEMBLY ▲

PAYLOAD SCHEDULE REQUIRING SERVICING AT STATION

CONCLUSIONS

The OTV hangar is planned to be operational in the same year as LDR assembly: 1997. Therefore there is a critical issue on the location of these two large program hardware systems on the station. Both of these are slated to use the region between the two keels on the lower boom. The LDR is thus not the only large experiment to utilize this part of the station.

The SIRTF precedes the LDR in schedule and utilizes the same servicing technology for cryogen transfer. Thus LDR is not pioneering this process or schedule. The location of servicing is probably different for the two payloads, however.

PAYLOAD SCHEDULE REQUIRING SERVICING AT STATION CONCLUSIONS

Lockheed

- OTV HANGAR MISSION YEAR IS SAME AS LDR ASSEMBLY: YEAR 5: 1997
- SIRTF SERVICED MORE FREQUENTLY THAN LDR: 1-1/2 VERSUS 2 YEARS
  - AND BEGINS EARLIER: 1994 VERSUS 1997
  - AND REQUIRES CRYOGEN TRANSFER

THEREFORE: LDR NOT "PIONEERING" THIS PROCESS FOR SPACE STATION, EXCEPT:
SERVICING IS AT LARGE ASSEMBLY PORT WHEREAS SIRTF IS IN SERVICING BAY

LDR LARGE STRUCTURES ASSEMBLED AT SPACE STATION

This chart lists the large structures scheduled for assembly on space station. LDR is not the only very large structure to be assembled although it is one of the earliest large free-flyers scheduled for assembly. LDR assembly probably also requires more precision then most of the other large structures.

LDR LARGE STRUCTURES ASSEMBLED AT SPACE STATION

PAYLOAD NO.	PAYLOAD NAME	ASSEMBLY YEAR NO.	PAYLOAD LOCATION	ASSEMBLY SITE LOCATION	DIMENSION (M)
SAAX 0020	LDR	5	4	LSAA*	30X25X25
SAAX 0501	EXPT'L GEO PLATFORM	7	4	LSAA	50X50X50
SAAX 0503	M-SAT-B	3	4	LSAA	45X20X10
SAAX 0504	M-SAT-C	7	4	LSAA	60X50X50
SAAX 0309	SETI GEO-ANTENNA	8	4	LSAA	100X10XX
S 009	SOLAR ACTIVITY MONIT	8	5	LSAA	6X3X2
C 005	TD OF LG GEO SAT	7	4	LSAA	0.5X10X25

LARGE STRUCTURES FOR ASSEMBLY IN PLACE: EXTERNAL ATTACHED, UNPRESSURIZED

TDMX 2212	MULTI ANT'A BEAM PAT	3	3	AT SITE	55
TDMX 2153	SOLAR DYN POWER	1	3	AT SITE	29
TDMX 2061	LARGE SCALE STRUCT'R	1	3	AT SITE	28
TDMX 2542	TETHERED CONST'N	3	3	AT SITE	15
TDMX 2543	TETHERED TRANSP'N	6	3	AT SITE	15
E 002	TEST SENSOR TECHNOL.	4	3	AT SITE	12

CONCLUSIONS:

1. LDR NOT A DRIVER OF LARGE STRUCTURE ASSEMBLY AREA DESIGN
2. AT LEAST 5 OTHER FREE-FLYERS PLANNED FOR ASSEMBLY
3. AT LEAST 6 VERY LARGE ATTACHED PAYLOADS ASSEMBLED ON STATION
4. ONLY ONE FREE-FLYER IS ASSEMBLED PRIOR TO LDR

* LARGE STRUCTURE ASSEMBLY AREA

LDR CHECKOUT ACTIVITIES

The checkout of the LDR after assembly at the Space Station will be in two parts: while attached to the station, and while free-flying near the station. The activities while attached to the station include functional checks for which problems can be corrected easily and for which there is no time criticality due to power or thermal constraints.

The solar arrays will be deployed while the spacecraft is still powered by the station, and the electrical system will be ensured of working before the spacecraft is released. The same is true of the science instruments. There will also be the initial optical alignment while at the station.

The assembled LDR, attached to the OMV, will then be deployed, separated from the OMV near the station, and the checkout process will continue. The checkout procedure will include the subjects shown on the chart. If fundamental problems occur the OMV will retrieve the LDR and return it to the station for detailed inspection and repair.

Lockheed

LDR CHECKOUT ACTIVITIES

WHILE ATTACHED TO SPACE STATION:

- OPTICS ALIGNMENT
  - SEGMENT ALIGNMENT AND FOCUS
  - OPTICAL TRAIN
  - CHOPPING SYSTEM
- FUNCTIONAL CHECK OF SCIENCE INSTRUMENTS (SI)
  - CRYO SYSTEM
  - NOISE LEVELS, DYNAMIC RANGE, SCAN MECHANISMS
- SPACECRAFT FUNCTIONAL CHECK
  - EPS ACTIVATIONS (INCLUDES SOLAR ARRAY DEPLOYMENT)
  - ACS AND PCS ACTIVATION
  - C&DH
  - THERMAL CONTROL SYSTEM

FREE-FLYING NEAR SPACE STATION:

- TELESCOPE AND SI FUNCTIONAL CHECK
- ALL SPACECRAFT SUBSYSTEMS
- MIRROR TEMPERATURE AND GRADIENTS

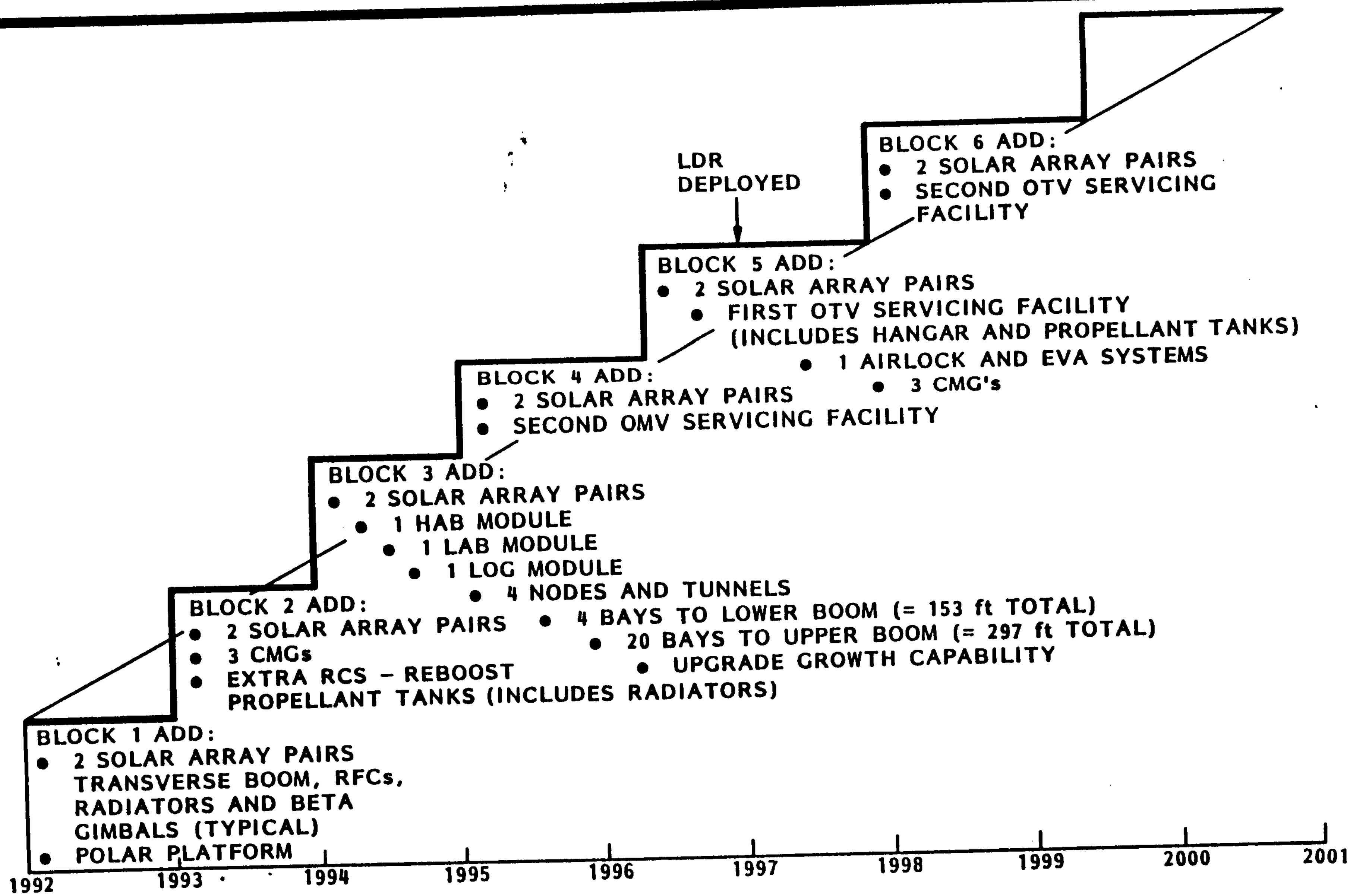
SYSTEM GROWTH

The major Space Station growth items are indicated for each year of the ten year growth period. The LDR is scheduled to be deployed in the sixth year - 1997 in the figure. Its relation to other items on the station is seen in the figure. The LDR is to be assembled and serviced in the Large Structures Assembly Area of the station. This is located on the lower boom of the dual keel configuration, preferably on the station centerline.

The timing and size of the OTV servicing facility is important to LDR since it also is planned to be located at the lower boom, and its size is of the same order as the assembled LDR. The chart indicates the first OTV servicing facility will be present in the same year as LDR deployment. Hence there is a potential real estate conflict. The secondary choice for LDR location is in the same region, except offset from the boom, as indicated in other charts.

Lockheed

SYSTEM GROWTH

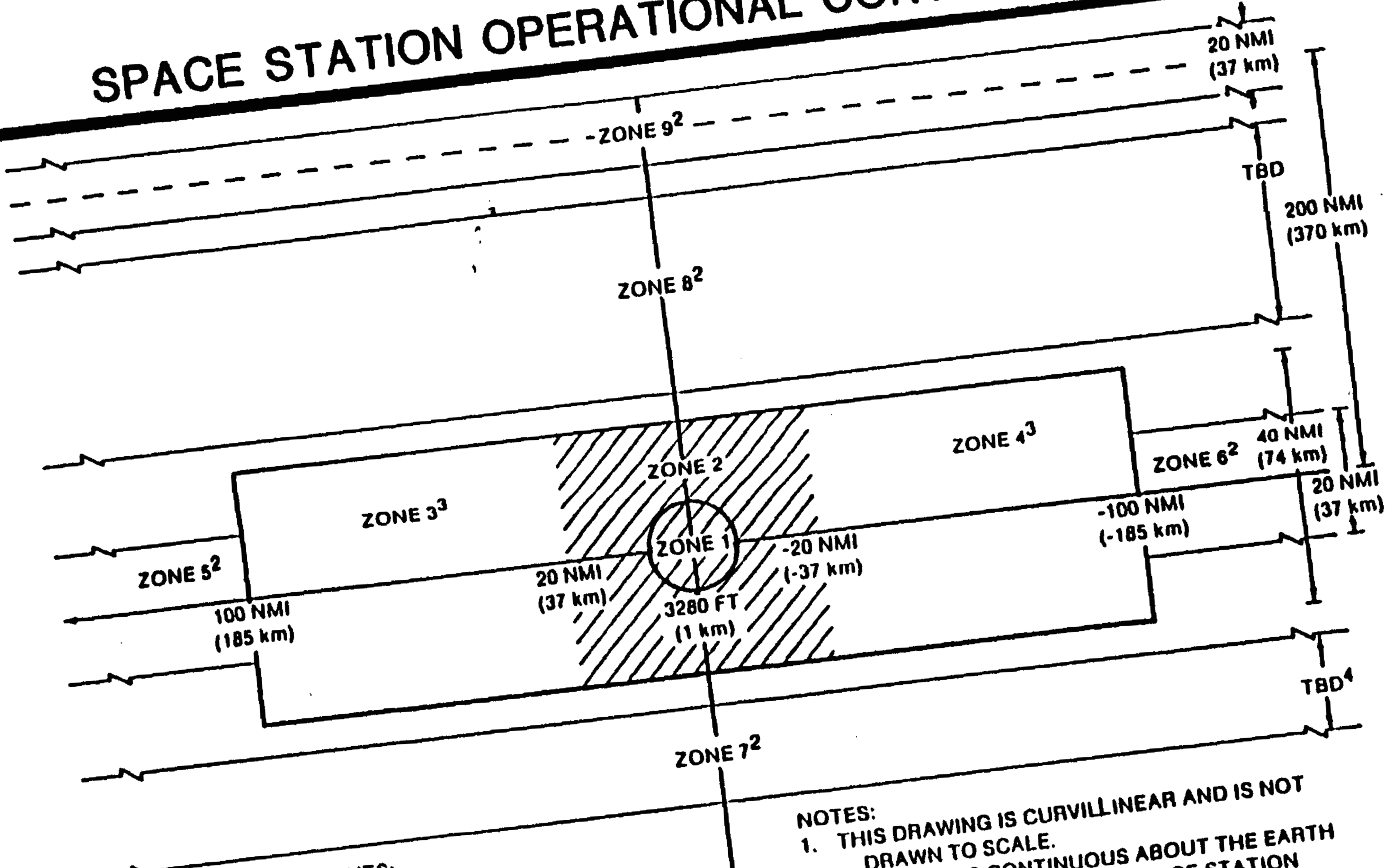


SPACE STATION OPERATIONAL CONTROL ZONES

There are different operational control zones for the station. These allow standardized flight and crew planning and operations. Each zone is dedicated to a specific type of operation. The zones are defined in the figure.

In Zone 1 are stationkeeping, flyarounds and final approaches/berthing. The LDR would be checked out while in this zone. Zone 2 is defined such that the station acquire active command/control/track of any unmanned vehicle in the zone. Departure of LDR from the station occurs in Zone 3. Rendezvous with the Station by the OMV/LDR occurs in Zone 4. The other zones are not directly relevant to LDR.

SPACE STATION OPERATIONAL CONTROL ZONES



ZONE ASSIGNMENTS:
1. PROXIMITY OPERATIONS ZONE
2. CONTROL ZONE
3. DEPARTURE ACTIVITY ZONE
4. RENDEZVOUS ACTIVITY ZONE
5. LEADING COORBITING SATELLITE ZONE
6. TRAILING COORBITING SATELLITE ZONE
7. LOWER NON-COORBITING SATELLITE ZONE
8. UPPER NON-COORBITING SATELLITE ZONE
9. PARKING ORBIT ZONE

NOTES:
1. THIS DRAWING IS CURVILLINEAR AND IS NOT DRAWN TO SCALE.
2. THIS ZONE IS CONTINUOUS ABOUT THE EARTH
3. THIS ZONE BEGINS AT THE SPACE STATION
4. THE MINIMUM OPERATING ALTITUDE FOR THIS ZONE IS ~ 100 NMI (~185 km)
5. ZONES 2,3,4,5, & 6 EXTEND ~ ±9 km(±5 NMI) OUT-OF-PLANE
6. ZONES 7,8 AND 9 ARE SPHERICAL SHELLS CENTERED ABOUT THE EARTH

LDR LOGISTICS AND ASSEMBLY SCENARIO: TOP-LEVEL

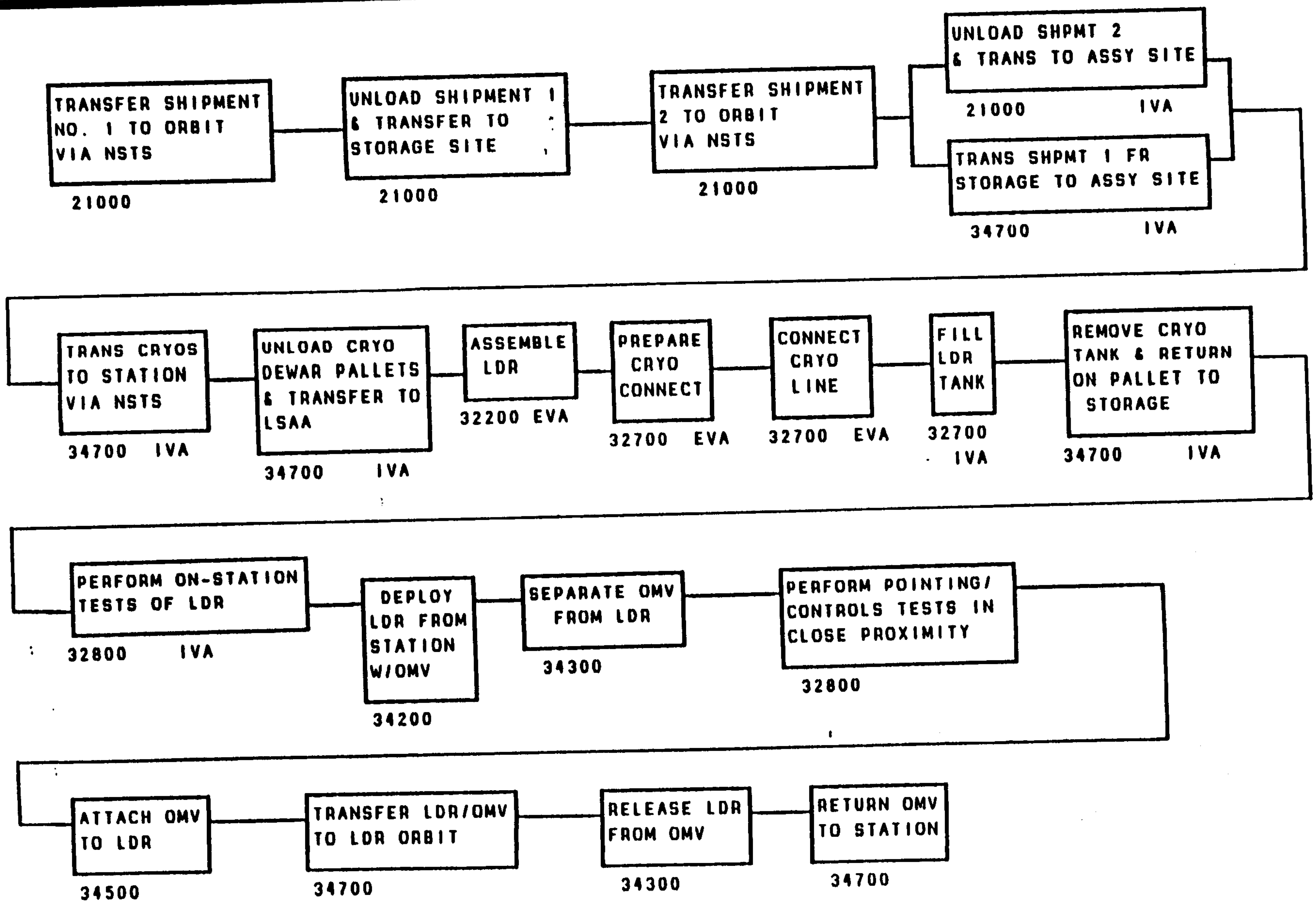
The transfer of the LDR sub-assemblies to the station will be in tow shuttle loads. The first will be stored in an enclosed site, powered with survival heaters as necessary. It is possible that no heaters will be required on a solely structural cargo.

The second shipment will be taken directly to the Large Structure Assembly Site and the first shipment will be taken from its storage site there also. The assembly process will begin, and will include cryogen transfer.

The on-station checkout will take place after assembly and cryogen loading, and after mating to the OMV. The OMV will be used to deploy the LDR from the station and then close proximity tests will be conducted, with the OMV separated from LDR.

Upon completion of the tests, the OMV will be reconnected and the LDR will be transported to its operational orbit. The OMV will be returned to the station.

LDR LOGISTICS AND ASSEMBLY SCENARIO: TOP-LEVEL



LDR-UNIQUE SPACE STATION REQUIREMENTS

There are few requirements which are unique to LDR. Within the over-300 payloads and satellites in the Space Station Mission Requirements Data Base are ones which exceed LDR in mass, volume and many of the other parameters shown. The crew times required for assembly and servicing are large for LDR, but are exceeded by 5 others for EVA time and 34 others for IVA time, per the data base.

LDR is unique in that it may be the first to require extensive fluid (cryogens and propellant) transfer in the region of the lower boom, outside an enclosed area. That will be the Large Structures Assembly Area. These fluids may be transported to the area by moveable pallet.

LDR may have unique contamination control requirements and design solutions due to its size. These may require special enclosures of each primary mirror segment, or they may require a total enclosure of the sunshield interior.

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LDR-UNIQUE SPACE STATION REQUIREMENTS

LDR MASS	– FIFTH IN PRESENT MRDB	NONE
LDR VOLUME	– SIXTH IN PRESENT MRDB	NONE
ASSEMBLY	– AT LARGE STRUCTURES ASSEMBLY SITE	NONE
SERVICING	– CRYOGEN/DIRECT TRANSFER	LARGE VOLUME
SPACE STATION CONTROL	–	NONE
THERMAL IMPACT	–	NONE
ELECTRICAL/DATA	–	NONE
FLUID TRANSFER	– TRANSFERRED BY CART TO SITE	POSSIBLE LOCATION
CREW EVA	57 – LARGEST ≥ 60	NONE
CREW IVA	20 – LARGEST ≥ 25	NONE
AUTOMATION/ROBOTICS	– IOC TECHNOLOGY	NONE
CONTAMINATION CONTROL	– NOT CRITICAL	SURFACE CLEANLINESS

Lockheed

OPERATIONS

L. WEAVER

LDR ASSEMBLY ANALYSIS OVERVIEW

The objectives of the LDR assembly analysis were:

- Develop a viable assembly concept using any practical combination of IVA, EVA, and robotic techniques, and pursue the concept to depth sufficient to demonstrate credability.
- Identify the assembly support requirements
- Determine the assembly timelines

The initial phase of the study effort was directed to interacting with design engineering to develop a basic assembly concept which was crew-compatible. The second, and largest, portion of the study effort was used to perform a detailed assembly analysis from the crew involvement point of view. This task defined crew tasks, timelines for each step, and identified station-provided and LDR-specific assembly support equipment requirements.

The final two phases of the assembly study effort briefly examined checkout and activation requirements, and servicing requirements, to ensure that the LDR configuration selected, and the assembly process, were compatible with the known requirements for activation, checkout, and servicing. No significant problems were identified.

LDR ASSEMBLY ANALYSIS OVERVIEW

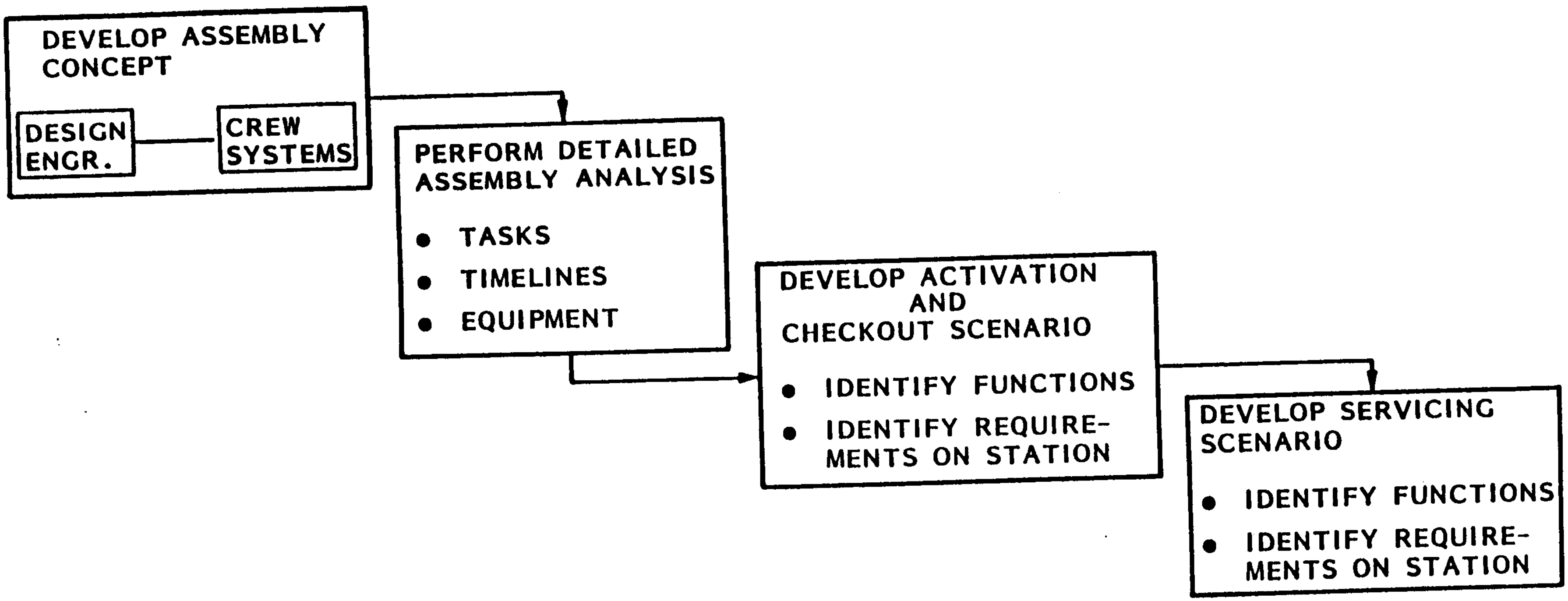
STUDY OBJECTIVES

(1) DEVELOP VIABLE ASSEMBLY CONCEPT

(2) IDENTIFY ASSEMBLY SUPPORT REQUIREMENTS
- STATION-PROVIDED EQUIPMENT
- STATION-PROVIDED UTILITIES
- UNIQUE LDR-PROVIDED EQUIPMENT

(3) DETERMINE EVA/IVA TIMELINES

STUDY OUTLINE



LDR TRANSPORTATION TO SPACE STATION

This chart lists major LDR components and how they might be scheduled for transportation to the space station in two shuttle trips.

LDR TRANSPORTATION TO SPACE STATION

KEY FEATURES:
(1) 20 m DIAMETER
(2) EXTENDABLE SUNSHADE SIDE PANELS
(3) EXTENDABLE SUNSHADE BASE PANELS
(4) EXTENDABLE TELESCOPE COVER PANELS
(5) ERECTABLE SUNSHADE/TELESCOPE COVER BASE STRUCTURE
(6) DEPLOYABLE SOLAR ARRAYS
(7) PASSIVE CONTAMINANT-PROTECTED ASSEMBLY
(8) ACTIVE CONTAMINANT PURGE SYSTEM

MAJOR EQUIPMENT ITEM LIST	SCHEDULED FLIGHT #	STS MANIFEST ITEM NUMBER
1.0 ASSEMBLY BASE (ROTATABLE)	1	
2.0 SUBSYSTEM/INSTRUMENT MODULE	2	
3.0 PRIMARY MIRROR RIB ASSEMBLY	2	
4.0 PRIMARY MIRROR RIB STRUT DISPENSER	2	
5.0 PRIMARY MIRROR HEX ASSEMBLY CONTAINER	2	
6.0 METERING STRUTS	2	
7.0 SECONDARY MIRROR ASSEMBLY	2	
8.0 SUNSHADE STRUCTURE DISPENSER	1	
9.0 SUNSHADE SIDE PANELS (6)	1	
10.0 SUNSHADE BASE PANELS (6)	1	
11.0 TELESCOPE COVER PANELS (6)	1	
12.0 CONTAMINANT PURGE SYSTEM	2	
13.0 SOLAR ARRAYS (2)	2	
14.0 COMMUNICATIONS ANTENNAS (2)	2	

ASSEMBLY FUNCTIONS: FLIGHT 1

Assuming that the LDR is launched in two dedicated shuttle missions, the majority of items launched on the first flight would be unloaded and stowed on the station. It is believed that these first launch items could be stowed externally on the station, and would not require environmental conditioning. Between the first and second flights, the LDR assembly base would be setup and activated, and selected LDR elements would be staged for assembly.

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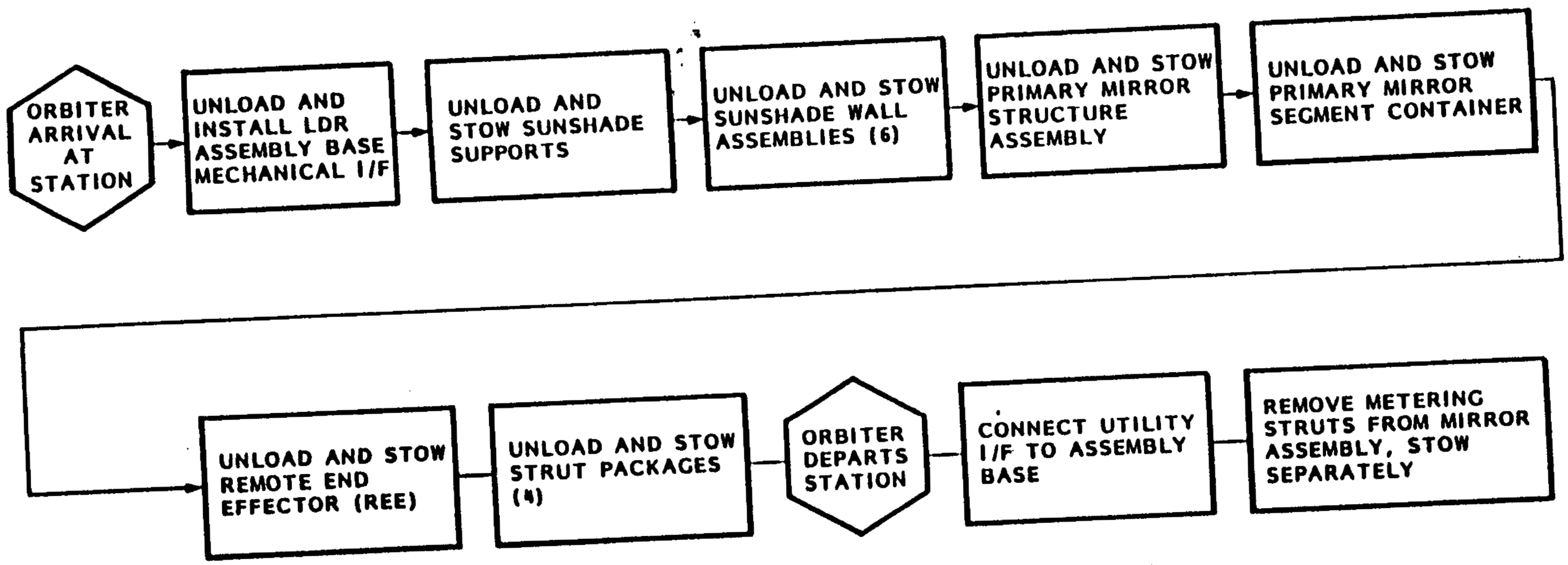
ASSEMBLY FUNCTIONS: FLIGHT 1

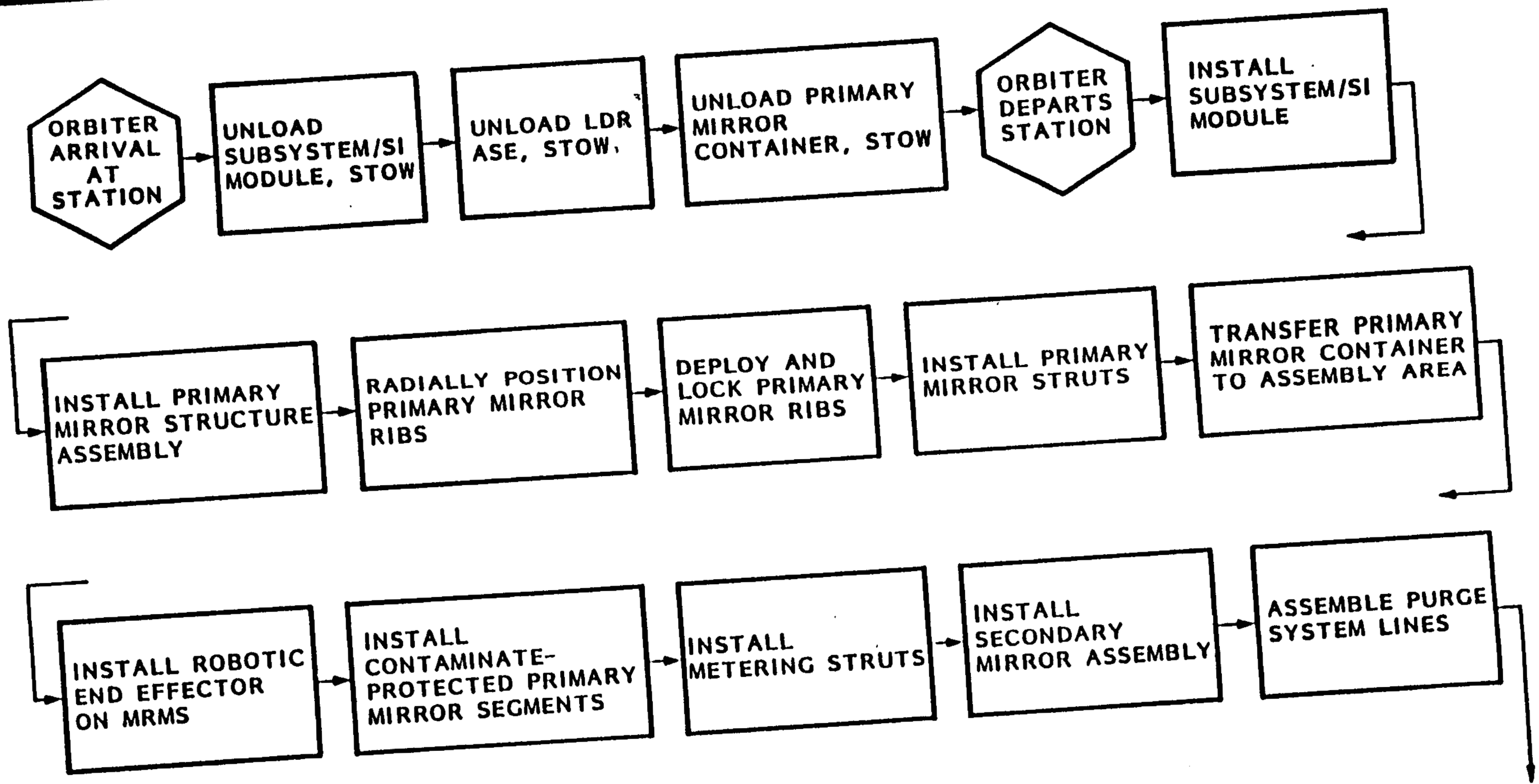


ASSEMBLY FUNCTIONS: FLIGHT 2 (1 of 2)

Items launched on the second flight would also be unloaded and stowed after orbiter arrival, to free the orbiter for departure. LDR assembly functions do not require the presence of the orbiter.

The primary assembly functions are outlined in block diagram form.

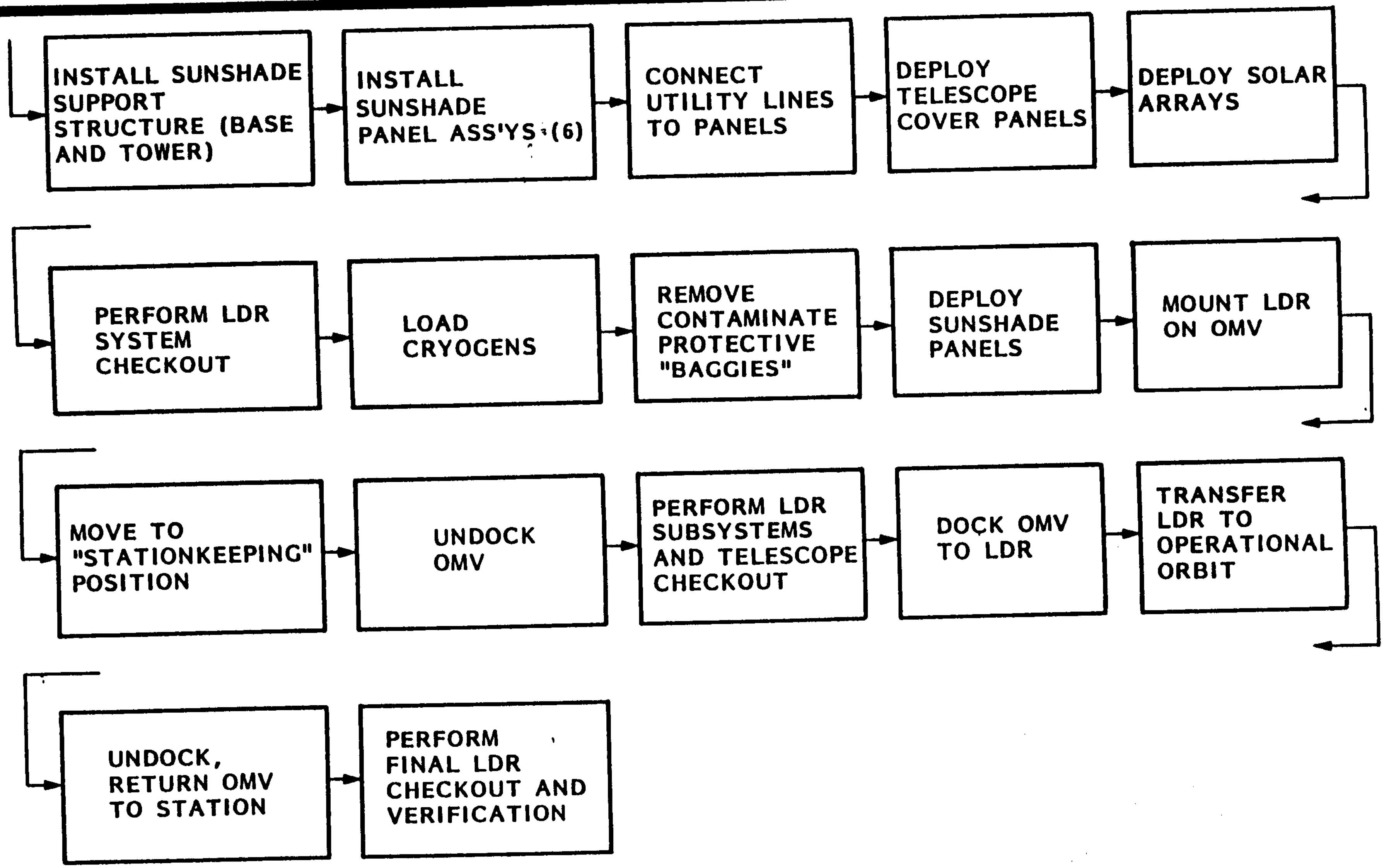
ASSEMBLY FUNCTIONS: FLIGHT 2 (1 OF 2)



ASSEMBLY FUNCTIONS: FLIGHT 2 (2 of 2)

The remaining primary assembly, checkout, activation, and deployment functions are outlined in block diagram form.

ASSEMBLY FUNCTIONS: FLIGHT 2 (2 OF 2)



FLIGHT 2 ASSEMBLY ACTIVITIES (EXCERPT)

This page illustrates the level of detail achieved in the assembly analysis.

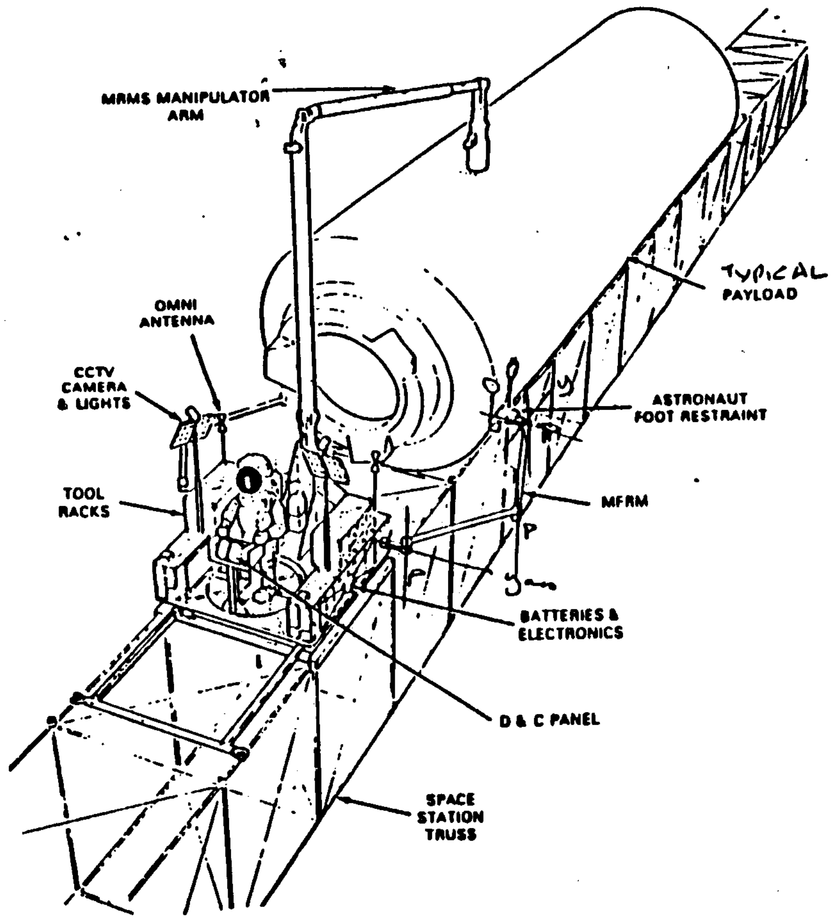
FLIGHT 2 ASSEMBLY ACTIVITIES (EXCERPT)

	OPERATIONS	MODE IVA	MODE EVA	STEP TIME (MIN) IVA	STEP TIME (MIN) EV1	STEP TIME (MIN) EV2	CUM TIME (MIN)	MMU 1	MMU 2	CUM DELTA V 1	CUM DELTA V 2	RMS	MRMS	PRECISION ROBOTIC ARM
		---	---	---	---	---	-----	-	-	-	-	---	---	--------
2.2.4	ATTACH MFR TO MRMS	X											X	
2.2.5	POSITION MFR TO ACCESS PRIMARY MIRROR RIB ASS'Y HUB WORKSTATION	X											X	
2.2.6	PREPARE FOR EVA	X												
2.2.7	EGRESS AIRLOCK		X		6	6								
2.2.8	TRANSLATE TO PRIMARY MIRROR ASS'Y HUB WORKSTATION		X		15	15	X X							
2.2.9	EV1 INGRESS MFR		X		1	(1)							X	
2.2.10	RELEASE RIB 1 RADIAL POSITION LOCKS		X		0.5	(0.5)							X	
2.2.11	MOVE RIB 1 TO DEPLOYMENT POSITION		X		2	(2)							X	
2.2.12	ENGAGE RIB 1 RADIAL POSITION LOCKS		X		1	(1)							X	
2.2.13	REPOSITION MFR TO ACCESS NEXT RIB		X		0.5	(0.5)							X	
2.2.14	RELEASE RIB 2 RADIAL POSITION LOCKS		X		0.5	(0.5)							X	
2.2.15	MOVE RIB 2 TO DEPLOYMENT POSITION		X		2	(2)							X	
2.2.16	ENGAGE RIB 2 RADIAL POSITION LOCKS		X		1	(1)							X	
2.2.17	REPOSITION MFR TO ACCESS NEXT RIB		X		0.5	(0.5)							X	
2.2.18	RELEASE RIB 3 RADIAL POSITION LOCKS		X		0.5	(0.5)							X	

COMPONENT TRANSFER USING MRMS

The assembly process is heavily dependent on an MRMS-like support equipment item, both for transport of items to and from storage locations prior to assembly, and to support the assembly process itself. A later chart illustrates the MRMS capabilities assumed for the assembly analysis.

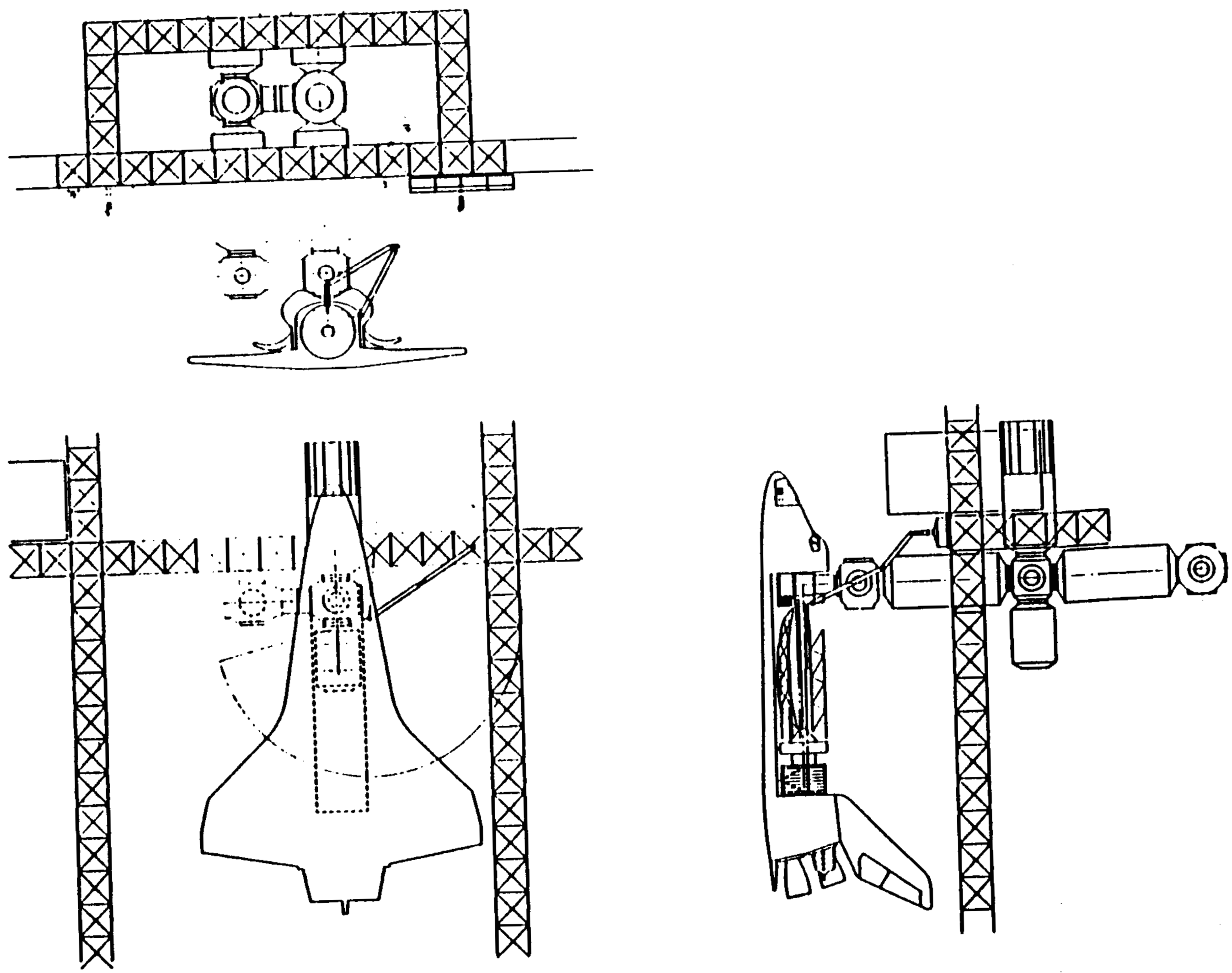
COMPONENT TRANSFER USING MRMS



RMS REACH CAPABILITY

The reach capability of the RMS was examined with respect to unloading LDR components from orbiter. Reach envelope requirements for the unloading and stowage activities are station configuration dependent, and tend to be generic rather than LDR specific.

RMS REACH CAPABILITY



MIRROR SEGMENT ASSEMBLY-(ROBOTIC) SEQUENCE

This task has been described in an earlier illustration also is shown again to demonstrate the overall mirror segment assembly sequence.

The first illustration (top left) shows the MRMS with the attached robotic end effector removing the first 4 meter hexagonal mirror segment from its storage location.

The second illustration (top center) shows the segment being moved into position by the MRMS with attached robotic end effector. At this point the MRMS is under control of an IVA crewmember.

The third illustration (top right) shows the segment being placed into position at the reflectors central position. The robot will have located itself for this precision task by attaching its positioning arm to a known locating point. Full robotic operation is possible after this location is assured.

The fourth illustration (bottom left) shows a segment being attached approximately half way between the center and the outside edge of the circular LDR structure. The assembly base can rotate the entire LDR when required to provide easy access to the MRMS/robot.

The final illustration (bottom center) shows a segment at the circumference being assembled.

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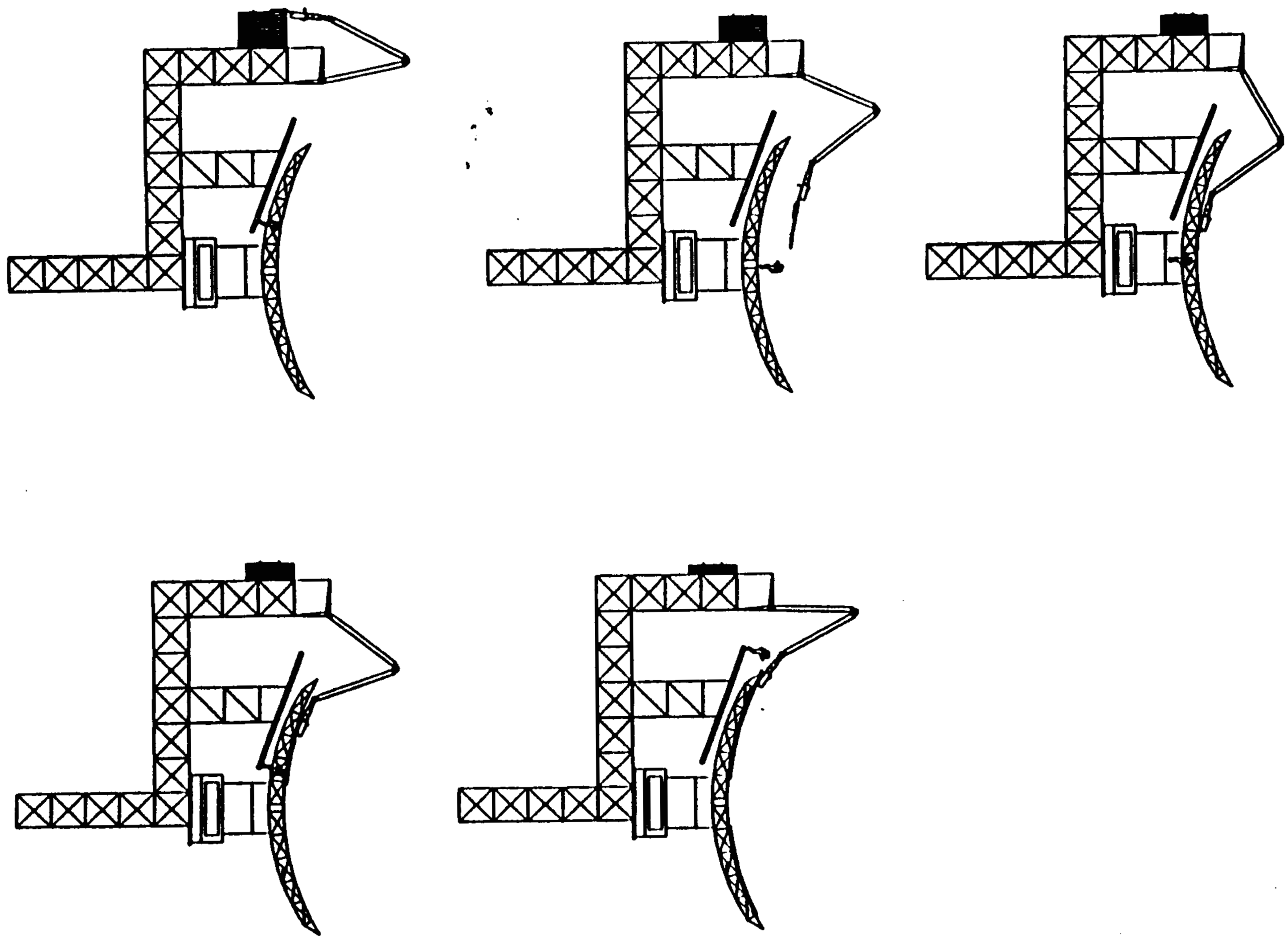
MIRROR SEGMENT ASSY – (ROBOTIC) SEQUENCE



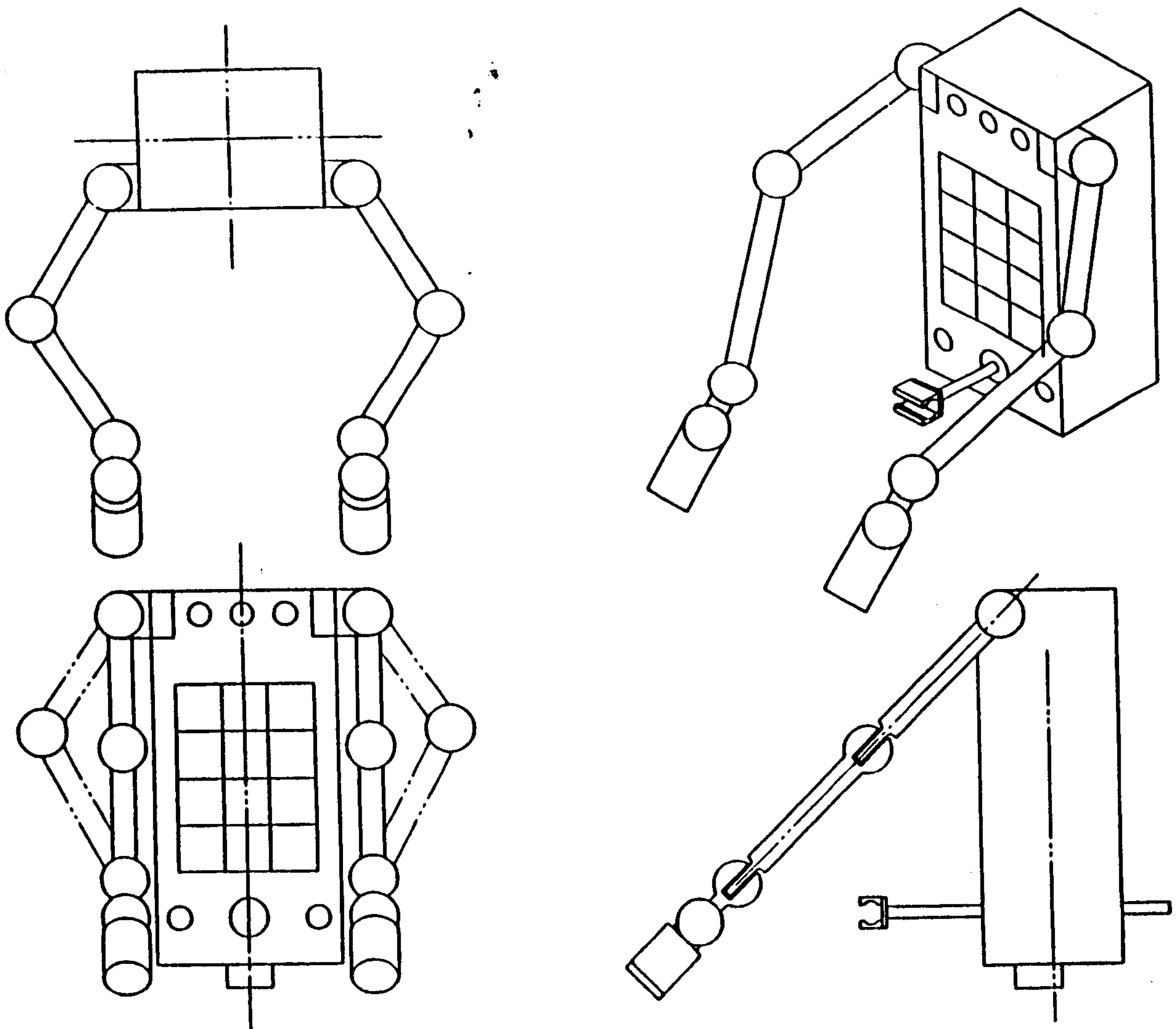
"TYPICAL" ROBOT FOR MAJOR MIRROR SEGMENT INSTALLATION

This illustration shows several views of the robotic end effector for the MRMS expected to be part of the space station IOC and available to assist in tasks such as LDR assembly. This robot must be attached to a known fixed position before it can perform useful tasks by manipulating appropriate end effectors in its own dual 6 axis robot arms. Data bases of station configuration and pre-programmed routines can be accessed to assemble robotic programs appropriate to the work required. Crewmember intervention (EVA or IVA) will be possible.

The robot can be carried to work locations by the MRMS. Attachment to the work site is accomplished and robotic routines performed. The robot will be equipped with vision and ranging sensors to determine location and provide information to supervising crew.

The robot will carry with it a variety of end effectors, tools and components suitable to the tasks being performed.

"TYPICAL" ROBOTIC FOR MAJOR MIRROR SEGMENT INSTALLATION



LDR SUMMARY ASSEMBLY DATA

This chart summarizes the major LDR activation and checkout functions.

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LDR SUMMARY ASSEMBLY DATA

ACTIVATION AND CHECKOUT OPERATIONS

- ACTIVATE AND CHECKOUT LDR ELECTRICAL SYSTEM (SS POWER)
- DEPLOY AND CHECKOUT LDR SOLAR PANELS
- DEPLOY SUNSHADE BASE PANELS (6)
- DEPLOY TELESCOPE COVER PANELS (6)
- ACTIVATE AND CHECKOUT LDR CONTROL SYSTEM (ATTACHED MODE)
- LOAD CRYOGENS
- CHECKOUT SCIENTIFIC INSTRUMENTS
- REMOVE MIRROR PROTECTIVE COVERS (38)
- DEPLOY SUNSHADE PANELS (6)
- MOUNT LDR ON OMV
- MANEUVER LDR INTO STATION-KEEPING POSITION
- UNDOCK OMV
- CONDUCT FINAL LDR SYSTEMS STATUS AND PERFORMANCE CHECKOUT
- DOCK OMV TO LDR
- BOOST LDR TO OPERATIONAL ORBIT
- UNDOCK OMV, RETURN TO SPACE STATION
- OPEN TELESCOPE PROTECTIVE PANELS (6)
- ACTIVATE SCIENCE INSTRUMENTS

DATA LDR SUMMARY ASSEMBLY

The chart summarizes the known requirements for station-provided equipment and utilities to support LDR assembly. Utility requirements have not been quantified; it is anticipated that a continuous level of power will be required after delivery of the LDR spacecraft on flight 2, for conditioning, and additional power will be required throughout the assembly process for rotating the LDR and operating the MRMS to position items for assembly.

It is anticipated that the LDR would be launched and assembled without cryogens onboard, and that cryogens would be loaded during the checkout and activation process.

Lockheed

DATA LDR SUMMARY ASSEMBLY

REQUIREMENTS FOR STATION-PROVIDED EQUIPMENT/UTILITIES

- STORAGE FOR PARTS PRIOR TO ASSEMBLY
  - EV?
  - SOME MAY REQUIRE ENVIRONMENTAL CONDITIONING
- ASSEMBLY SITE
  - SURFACE TO MOUNT ASSEMBLY BASE
  - UTILITY LINES TO ASSEMBLY SITE
  - MRMS ACCESS ALONG "L" PATH ALONG BASE AND ONE SIDE OF LDR
- MRMS-LIKE ASSEMBLY AID
  - MANIPILATOR (BOTH IVA AND EVA CONTROL)
  - SIMULTANEOUS MANIPILATOR AND MANNED MOBILE WORK PLATFORM CAPABILITY
  - SINGLE PLANE MOTION ADEQUATE
- MANNED MANEUVERING UNITS (2)
- IVA CONTROL CONSOLE FOR ACTIVATION AND CHECKOUT PHASE
- OMV
- PRECISION ROBOTIC ARM

LDR SUMMARY ASSEMBLY DATA

The chart summarizes the LDR assembly-related functions which are considered prime candidates for robotic implementation.

LDR SUMMARY ASSEMBLY DATA

AUTOMATION AND ROBOTICS FUNCTIONS

- UNLOAD COMPONENTS FROM SHUTTLE
- TRANSPORT TO TEMPORARY STORAGE SITE, PLACE IN STORAGE
- RETRIEVE FROM STORAGE, STAGE FOR ASSEMBLY OPERATIONS
- MFR ATTACH/DETACH FROM MRMS MANIPULATOR
- STRUT DISPENSER ATTACH/DETACH FROM MRMS/MFR
- PRIMARY MIRROR SEGMENT INSTALLATION
- MOBILE WORKSTATION REPOSITIONING BETWEEN REPETITIVE TASKS

LDR REFLECTOR ASSEMBLY APPROACH

The primary mirror structure is transported to the assembly site in the launch stowage configuration (main ribs stowed, Section A-A) and mounted to the LDR spacecraft. The structure is transported by the MRMS under IVA control. Mechanical attachment to the LDR spacecraft can be accomplished either by the MRMS under IVA control, or with EVA assistance. Connection of utility lines across this interface is anticipated to be an EVA function.

Rotation of each main rib to the proper radial position for deployment (main ribs rotated, Section B-B) can be accomplished manually by an astronaut in a Manipulator Foot Restraint (MFR) mounted on the MRMS manipulator. Main rib deployment to the fully open and locked position is also accomplished manually by an astronaut in an MRMS-mounted MFR. The main rib assembly (and the LDR spacecraft upon which it is mounted) require rotation periodically to assist the crewmember in accessing successive main ribs.

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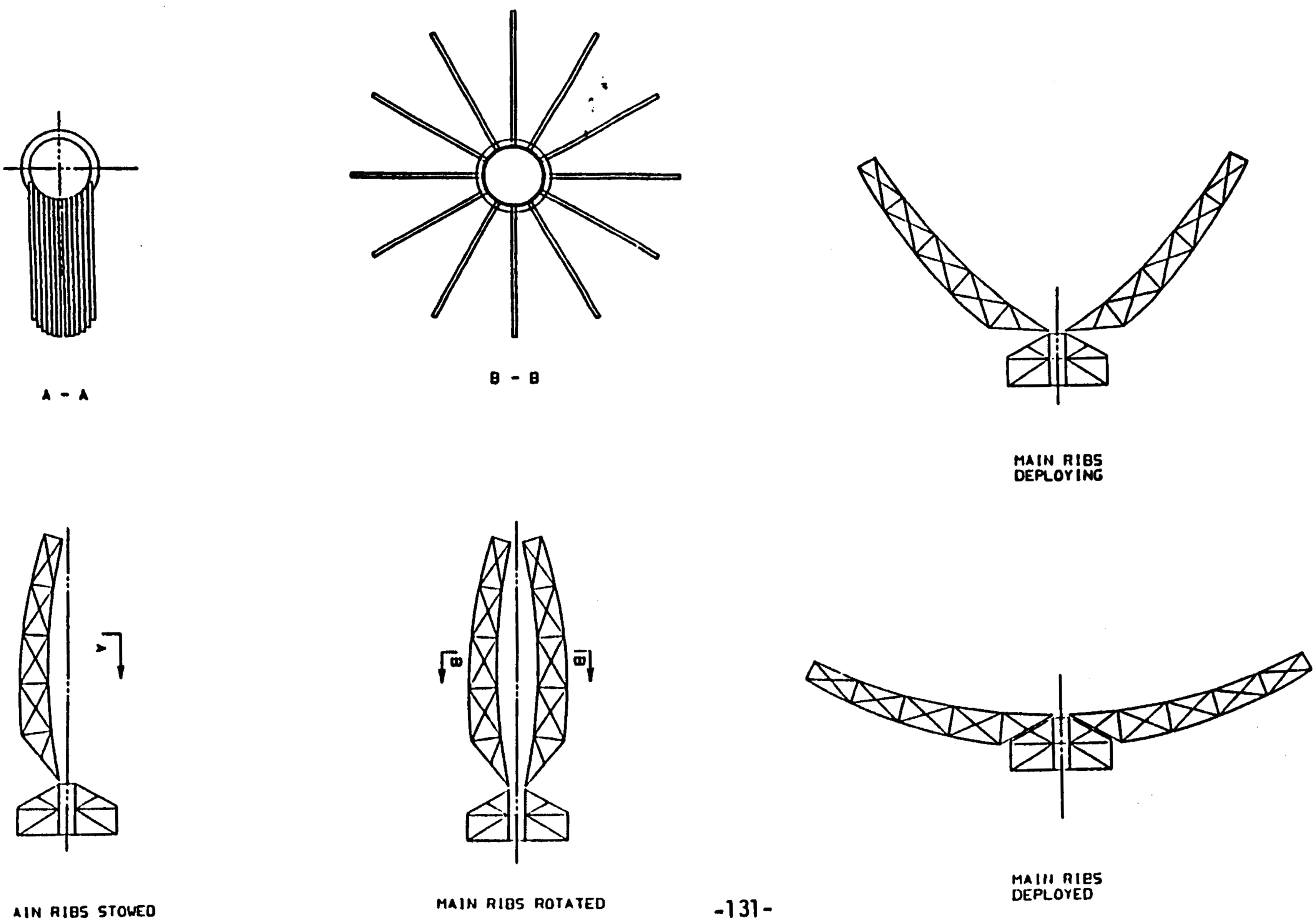
LDR REFLECTOR ASSEMBLY APPROACH



LDR REFLECTOR ASSEMBLY APPROACH

Figure 1 illustrates the 12 main ribs of the reflector, mounted on the cylindrical LDR spacecraft, deployed and locked. Figures 2,3, and 4 illustrate the installation of the circumferential struts on both the inner and outer faces of the reflector to complete the assembly of the reflector primary structure. The circumferential struts are manually installed by an EVA crewmember in an MRMS-mounted MFR, with a strut dispenser also mounted to the MFR adjacent to the crewmember. The LDR spacecraft/reflector assembly requires periodic rotation during the strut installation to permit the crewmember to access successive ribs.

This assembly concept, as it would apply to the buildup of a space station primary keel structure, was successfully demonstrated under pressure-suited, neutral buoyancy conditions by Lockheed during 1985. The assembly time estimates reported at the conclusion of this section are based on the neutral buoyancy test data, adjusted by one of the test crewmembers as necessary to accommodate the reflector structural geometry.

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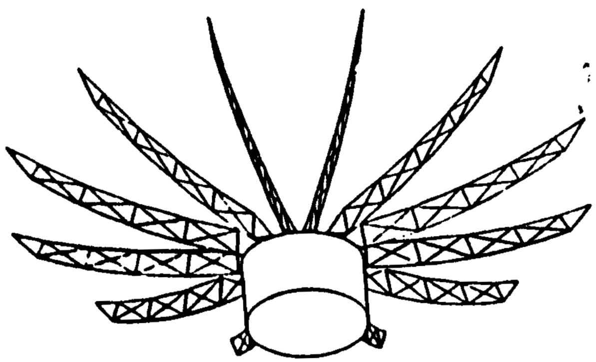
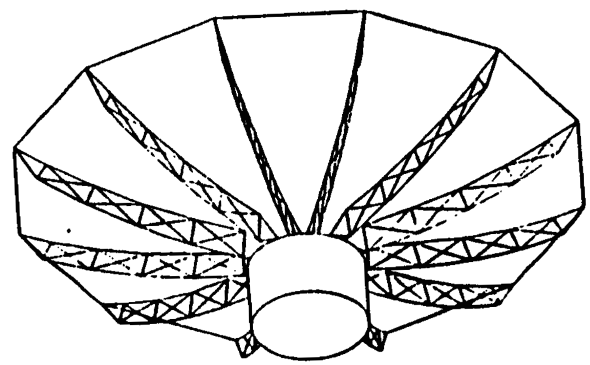
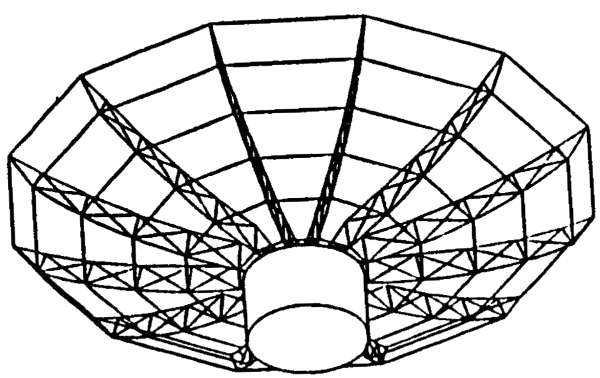
LDR REFLECTOR ASSEMBLY APPROACH



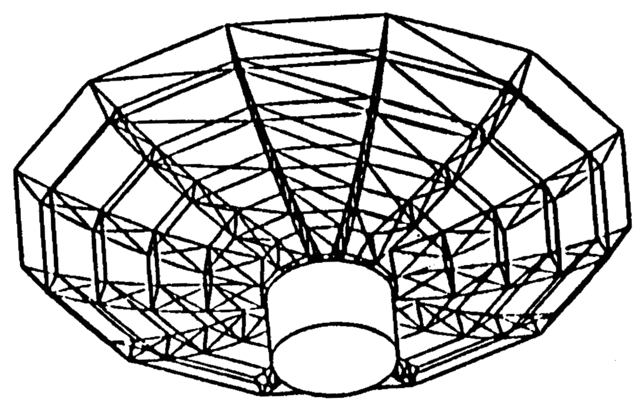
① DEPLOY 12 MAIN RIBS



② ATTACH OUTER RIM STRUTS



③ ATTACH OUTER FACE CIRCUMFERENTIAL STRUTS



④ ATTACH INNER FACE CIRCUMFERENTIAL STRUTS

LDR REFLECTOR ASSEMBLY APPROACH (Second chart)

Installation of the hexagonal primary mirror segments onto the structure is accomplished by a combination of IVA and robotic functions. EVA is not required except as backup.

Mirror segments are transported by the MRMS to the assembly site in a carrier structure, with the optical surfaces further protected by individual protective covers. The carrier structure is mechanically attached at the assembly site, and the MRMS manipulator is then used in conjunction with a precision robotic end effector to install the mirror segments. Each installation operation requires the following steps:

- An IVA crewmember operating the MRMS engages the precision robotic end effector to a reference point on the mirror segment carrier.
- The robotic system removes the mirror segment from the carrier.
- An IVA crewmember operating the MRMS positions the precision robotic end effector to a reference point on the reflector structure.
- The robotic system installs the mirror segment on the reflector structure.
- An IVA crewmember repositions the robotic end effector to the reference point on the mirror segment carrier.

The reflector must be rotated periodically to permit access to all surface areas for mirror segment installation.

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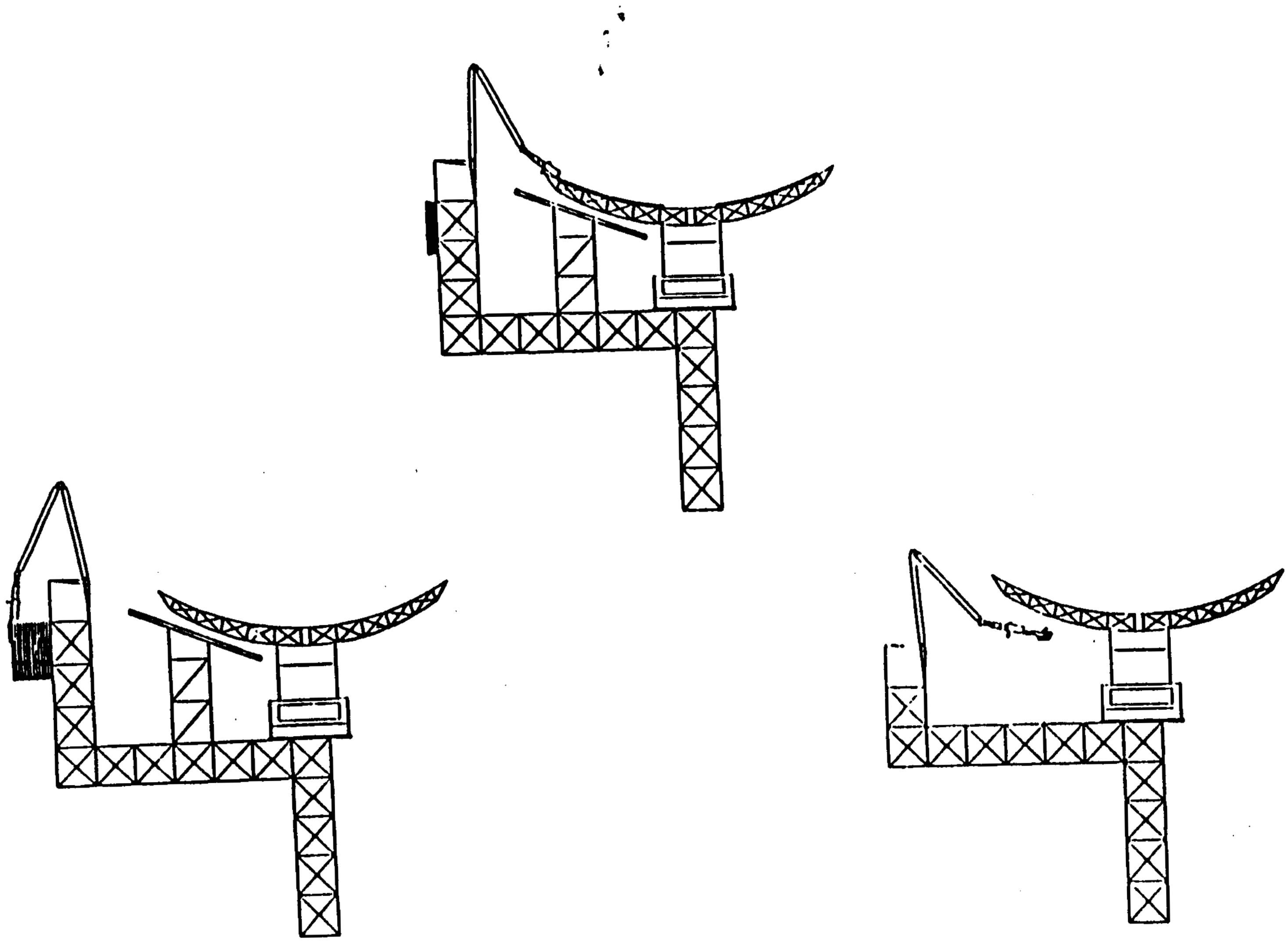
LDR REFLECTOR ASSEMBLY APPROACH

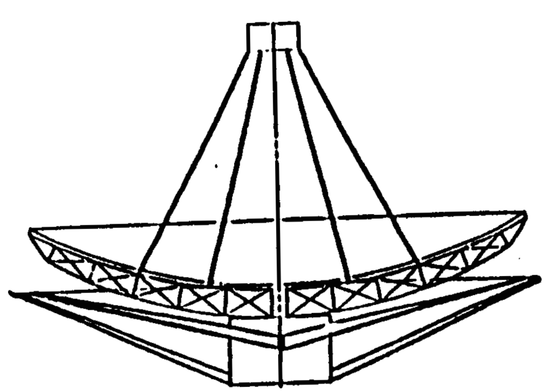


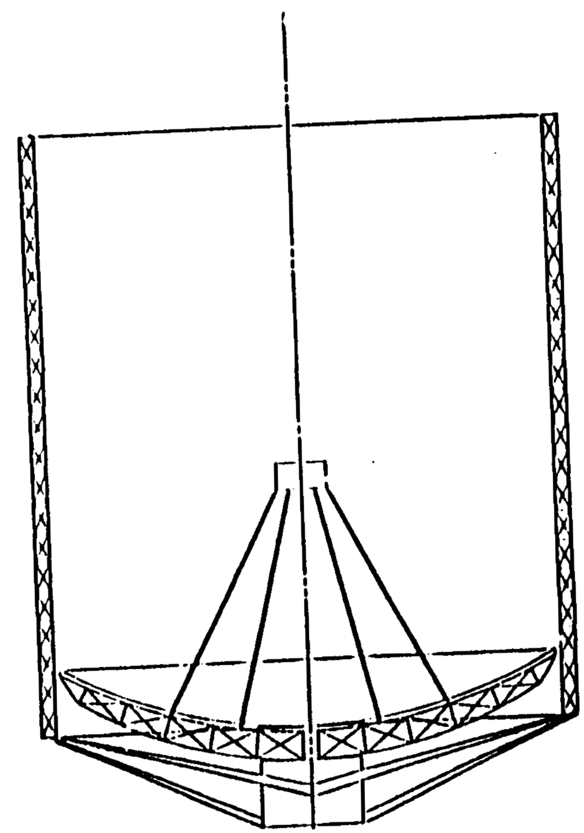
LDR REFLECTOR ASSEMBLY APPROACH (Third chart)

The assembly analysis assumes that the sunshade assembly requires a mounting base separate from the reflector structure, for stability purposes. The approach to establishing this base is to construct six three-member pyramids, equally spaced around the LDR spacecraft, to establish a hexagonal base for mounting the six deployable sunshade panels. The pyramidal structures are assembled by EVA, using stacked, tapered column structural members. The assembly work is performed by a crewmember in the MRMS-mounted MFR, with the tapered column structural members positioned adjacent to the crewmember in a dispenser. A sunshade forward structure is required for sunshade stability; it is a simple erectable structure assembled by EVA.

The six individual sunshade panels and actuators are positioned by the MRMS for installation. Mechanical and electrical connections are accomplished by EVA.

LDR REFLECTOR ASSEMBLY APPROACH





ASSEMBLY SUPPORT EQUIPMENT

The LDR assembly analysis assumed the availability of a station-based MRMS, featuring a shuttle RMS-like primary manipulator and two side-mounted mobile EVA workstations. This or an equivalent aid is essential to the assembly process, for unloading, storing, and staging LDR equipment items for assembly, as well as being a key element in the IVA, EVA, and robotic assembly processes.

The chart illustrates first cut MRMS requirements in the areas of primary functions, control, reach envelopes, and performance, as derived to support assembly of erectable space station structure and installation of utilities. The MRMS as illustrated was used in the LDR assembly analysis.

ASSEMBLY SUPPORT EQUIPMENT

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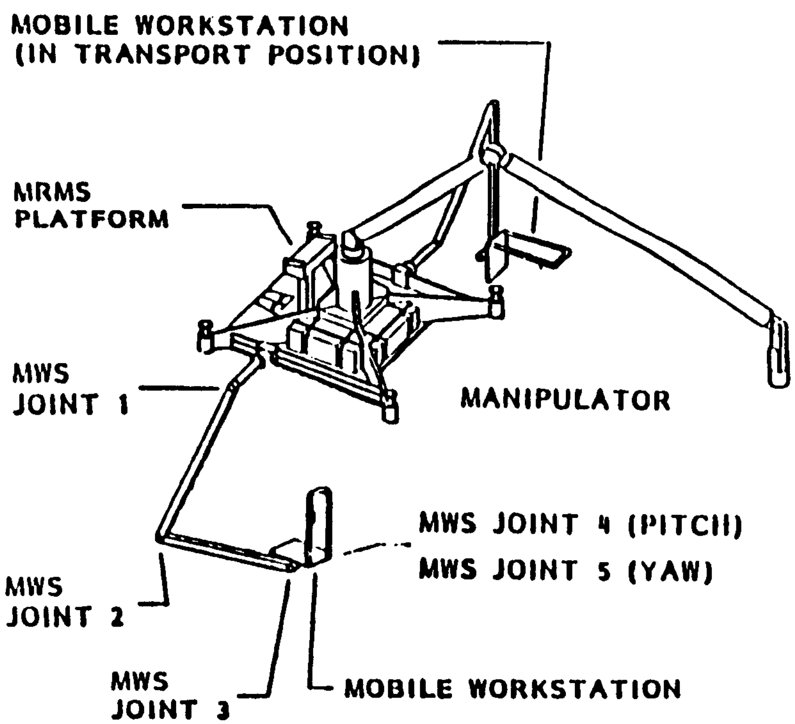
MRMS REQUIREMENTS



PRIMARY FUNCTIONAL REQUIREMENTS

1. TWO MOBILE WORKSTATIONS (MWSs)
2. ONE PLATFORM-MOUNTED MANIPULATOR
3. SELF CONTAINED POWER SYSTEM
4. PLATFORM CAPABLE OF FORWARD AND REVERSE TRAVEL IN 2 ORTHOGONAL DIRECTIONS
5. PLATFORM (INCLUDING "GRABBER BAR") CAPABLE OF ± 180° ROTATION
6. WORKSTATION-MOUNTED HARDPOINTS FOR DISPENSER ATTACHMENT

CONTROL REQUIREMENTS

	CONTROL SITE				
	EITHER MWS	MRMS PLATFORM	STATION	ORBITER	EARTH
1. MRMS TRANSLATION[1]	X	X	X	X[2]	
2. MOBILE WORKSTATIONS	X[4]	X[3]	X[3]	X[2, 3]	
3. MANIPULATOR	X	X	X	X[2]	
4. STATUS MONITORING, RECHARGING		X	X	X[2]	X
5. CCTV CONTROL AND DISPLAY	X	X	X	X[2]	

[1] TRANSLATION CONTROL IMPLIES: 1) MOTIONS IN ALL ORTHOGONAL DIRECTIONS, 2) ROTATIONAL CONTROL, 3) BRAKING FUNCTIONS

[2] REQUIRED ONLY PRIOR TO STATION MANNING

[3] REQUIREMENT LIMITED TO CAPABILITY TO COMMAND MWS TO TRANSPORT POSITION

[4] PREPROGRAMMED WORKSTATION POSITIONING CONTROL MODE REQUIRED ONLY FROM EACH WORKSTATION

REACH REQUIREMENTS

1. MANIPULATOR (TBD - USE EXISTING STS RMS CAPABILITIES)
2. EACH MOBILE WORKSTATION (MWS)
   - POSITION CREWMEMBER @ EACH OF 4 NODAL POSITIONS ON ONE SIDE OF ADJACENT BAY, WITH BODY PARALLEL TO MRMS FRAME
   - POSITION CREWMEMBER @ EACH OF 4 NODAL POSITIONS ON ONE SIDE OF ATTACHED BAY, WITH BODY PERPENDICULAR TO MRMS FRAME
3. JOINT RANGE REQUIREMENTS
   - MANIPULATOR TBD
   - MWS JOINT #1: SINGLE DEGREE OF FREEDOM - 360°
     - #2: SINGLE DEGREE OF FREEDOM - 360°
     - #3: SINGLE DEGREE OF FREEDOM - 270°
     - #4: SINGLE DEGREE OF FREEDOM - 180°
     - #5: SINGLE DEGREE OF FREEDOM - 360°

PERFORMANCE

1. MWS PLATFORM FORCES	TBD
2. MWS TRAVEL RATE:	≥1 FT/SEC
3. PLATFORM TRAVEL RATE:	≥0.15 FT/SEC
4. PLATFORM ROTATION RATE:	TBD

SUMMARY ASSEMBLY DATA

The results of the detailed assembly analysis are summarized for IVA, EVA, and robotic functions, for the assembly functions per se. Pre-assembly functions (i.e., unloading LDR components from the STS, temporarily storing them, staging them for assembly, assembly and activation of assembly support equipment, etc.) and post-assembly functions (i.e., activation, checkout, deployment, etc.) were not timelined, due to the heavy influence of the yet to be defined details of station geometry. Significant additional amounts of IVA time will be required to accomplish these functions; substantial crewmember time savings can be realized by use of robotics for these functions.

SUMMARY ASSEMBLY DATA

ASSEMBLY TIMELINES (min)*	IVA	EVA	ROBOTICS
UNLOAD AND TEMPORARY STORAGE OPERATIONS	TBD	TBD	
ASSEMBLY, ACTIVATE ASSEMBLY SUPPORT EQUIPMENT	TBD	TBD	
INSTALL SUBSYSTEMS/SCIENTIFIC EQUIPMENT MODULE	15	0	
INSTALL, DEPLOY PRIMARY MIRROR RIB ASSEMBLY	0	137	
INSTALL PRIMARY MIRROR RIB STRUTS/DIAGONALS	0	875	
INSTALL PRIMARY MIRROR SEGMENTS	612	0	864
INSTALL METERING STRUTS	0	16	0
INSTALL SECONDARY OPTICS	0	8	0
ASSEMBLE SUNSHADE BASE STRUCTURE	0	206	0
ASSEMBLE SUNSHADE FORWARD STRUCTURE	0	258	0
INSTALL SUNSHADE ASSEMBLIES	0	197	0
DEPLOY PRE-INSTALLED APPENDAGES	TBD	0	0
ACTIVATION	627	1696	864
CHECKOUT	(10.5 h)		
DEPLOYMENT		(28.3 h)	(14.4 h)

*TIMES DO NOT INCLUDE TRANSFERS TO/FROM STORAGE PERFORMED ROBOTICALLY OR UNDER IVA CONTROL

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TECHNOLOGY DEMONSTRATION MISSION

L. BANDERMANN

LDR TECHNOLOGY DEMONSTREATION MISSION (TDM)

A TDM was identified, sketched out and preliminary requirements were derived. This TDM will demonstrate in space the key LDR technologies identified in the chart. ROM cost estimates are about $50 Million, not counting possible technology developments, such as for composite mirror materials, and precursor activities, such as neutral buoyancy experiments.

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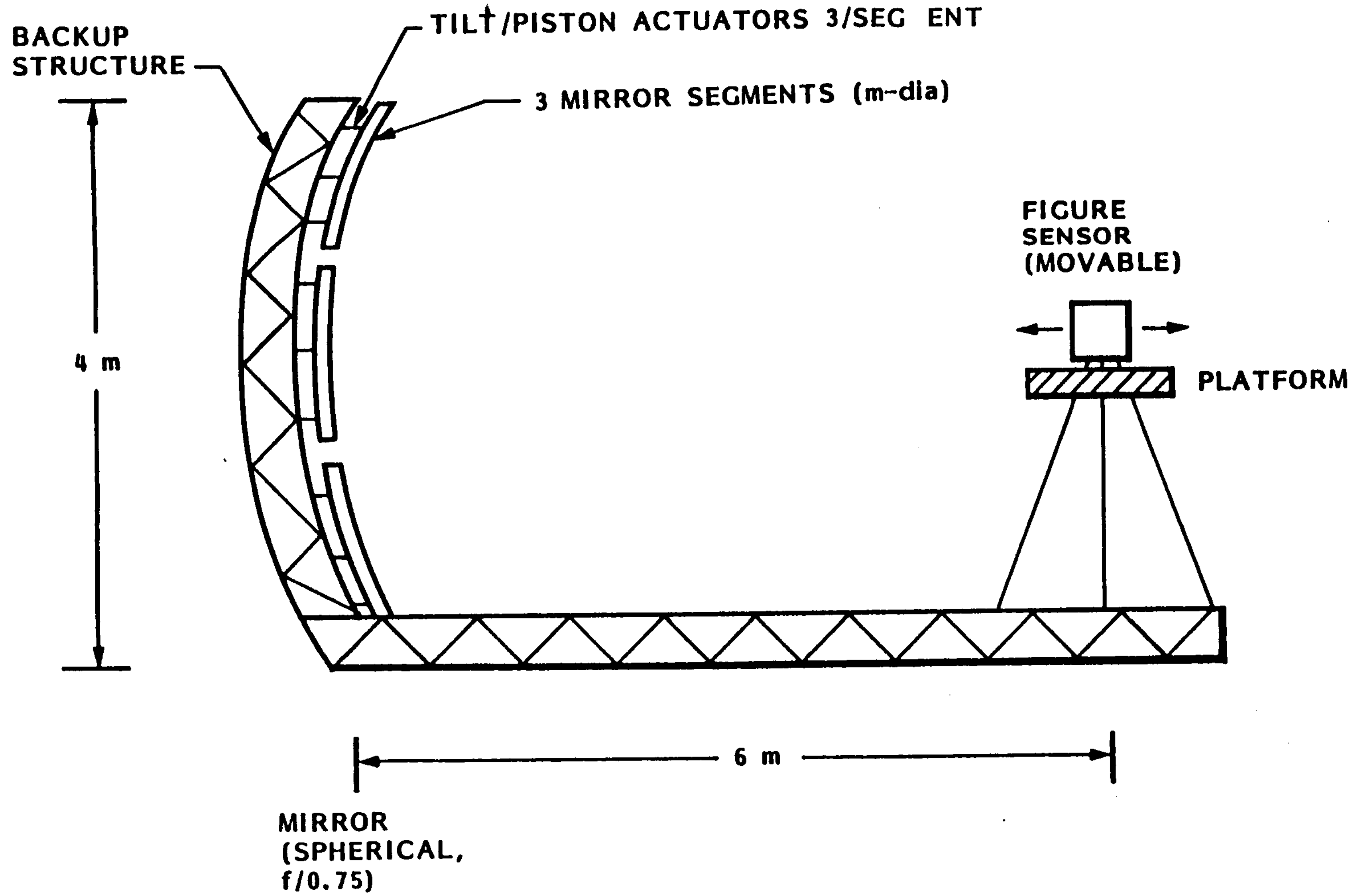
LDR TECHNOLOGY DEMONSTRATION MISSION (TDM)

- PURPOSE
  - VERIFY AND DEMONSTRATE KEY TECHNOLOGIES ON SUBSCALE, LOW-COST, SHUTTLE-BASED FLIGHT EXPERIMENT
- SPECIFIC GOALS
  - DEMONSTRATE MIRROR AND SUPPORT STRUCTURE ASSEMBLY IN ZERO-G ENVIRONMENT
  - DEMONSTRATE FIGURE CONTROL
  - DEMONSTRATE THERMAL CONTROL
  - VERIFY MIRROR AND STRUCTURE TECHNOLOGIES
- ESTIMATED WEIGHT, COST
  - 200 kg, $30,000,000
- PRECURSOR EXPERIMENTS AND DEVELOPMENTS
  - COMPOSITE MIRROR PANELS
  - NB ASSEMBLY

TDM 2421 TOP-LEVEL DESIGN OVERVIEW

The TDM consists of basically three elements: a 3-panel mirror assembly, an assembly and support structure and at figure measurement system. The TDM overall dimensions are chosen for easy packaging in the shuttle bay (e.g. the mirror diameter $\leq$ 4m). The support structure is collapsible for minimum stowed volume. The mirror panels have a spherical figure since the figure sensing technique is a center-of-curvature test. The panels are actuatable in tilt and piston. Heaters on the backs of the panels and on the structure are used to simulate a changing thermal environment. Actuators and heaters controlling the structure are optional.

TDM TOP-LEVEL DESIGN OVERVIEW



CENTER OF CURVATURE DIAGNOSTICS

A center of curvature test was selected for the TDM because it is one of the most simple yet effective optical tests that can be performed to measure optical figure. The test is only applicable to spherical reflectors, which are cost effective to produce since all segments have the same radius of curvature.

The experimental layout is shown in this chart in schematic form but approximately to scale. The light source is a laser diode or a similar low-power laser source. The light, after passing through suitable optics, a spatial filter (a pinhole) and, finally, a beamsplitter illuminates the mirror panels evenly. Part of the beam is, however, split off by the beamsplitter, reflected by the upper surface of the beamsplitter, and passes through to the sensor package. Part of that beam is diverted by another beamsplitter in the package and focused onto an imager, probably a CCD array. The other part passes through to the pupil plane detector, there interfering with the beam returned by the primary mirror.

The imager serves to center the three spots returned by the individual mirror panels, and focusing of the spot(s) is achieved by proper tilt/piston adjustments of the panels. The interferogram in the pupil plane is then evaluated to give detailed information about the figure of the three panels and the spatial distribution of the figure errors.

The components of this C-C sensor package are all state-of-the-art.

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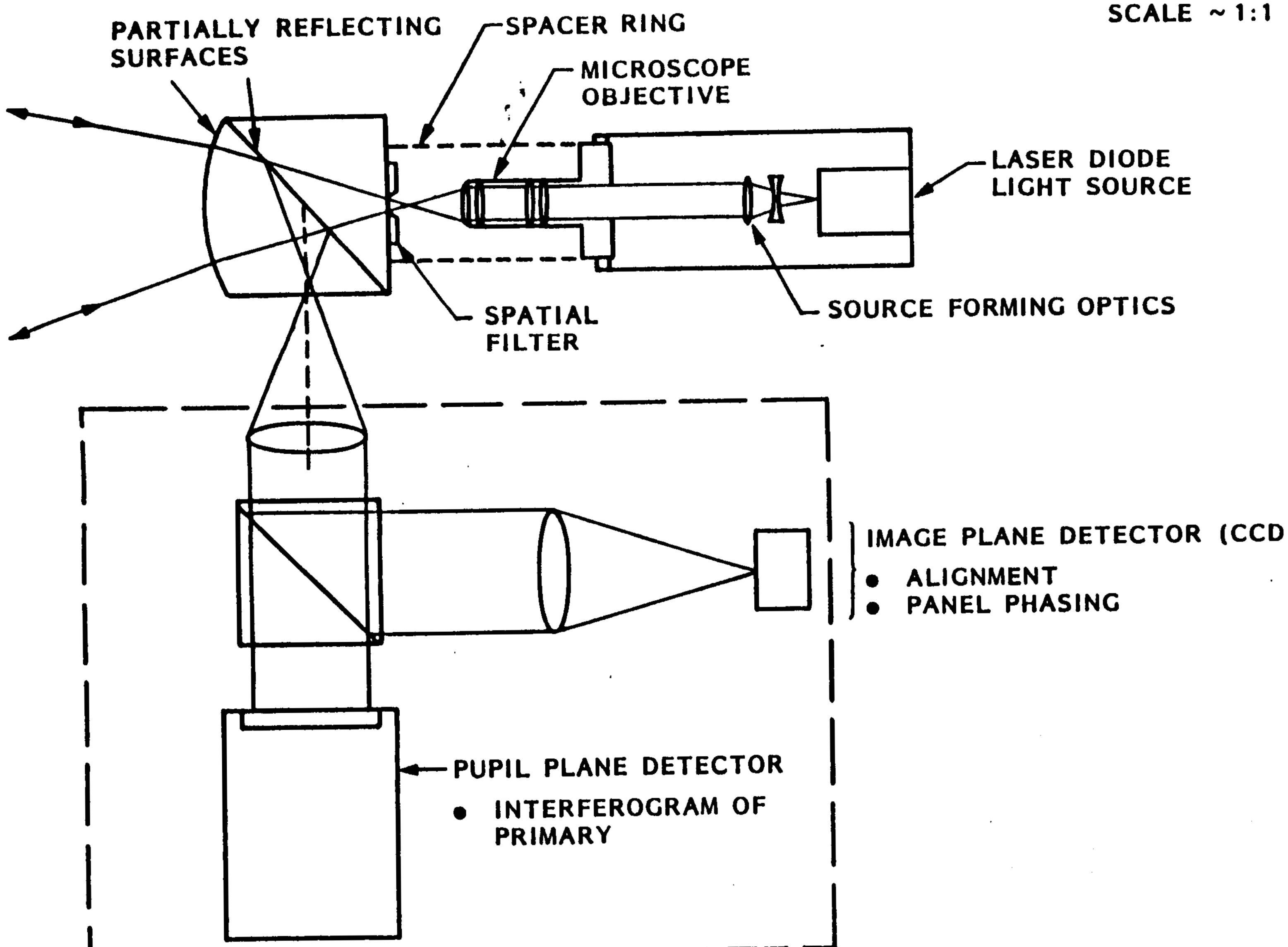
CENTER-OF-CURVATURE DIAGNOSTICS

SCALE ~ 1:1



ALIGNMENT TOLERANCES FOR C-C DIAGNOSTIC PACKAGE

Preliminary calculations show that the on-orbit alignment tolerances for the TDM are very generous and will be easily achieved. The tolerances do depend somewhat on the primary f/number.

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ALIGNMENT TOLERANCES FOR C–C DIAGNOSTIC PACKAGE

ASSUME f/1 PRIMARY

- CAPTURE RANGE
  - PANEL TILT: ± 1.4 mrad (CAN BE INCREASED)
  - PANEL PISTON: ± 2.4 mm
  - TOTAL DEFOCUS: ± 8 mm
  - TOTAL DECENTER: ± 6 mm

- ONCE CAPTURED

IMAGE PLANE
- PANELS ARE ALIGNED (TILT REMOVED) SEQUENTIALLY
- PANELS ARE PHASED SEQUENTIALLY
- TOTAL FOCUS REMOVED

PUPIL PLANE
- INTERFEROGRAM RECORDED

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RECOMMENDATIONS

W. ALFF

RECOMMENDATIONS

A technology demonstration mission compatible with TDM 2421, has been developed for LDR which will illustrate: (1) The feasibility of utilizing active optics in space (2) Assembly of an active optics structure (3) Utilization of light weight optics (4) Light weight truss technology. The concept presented namely measuring measuring and locating the center of curvature of each segment and positioning each segment so that the centers coincide is a relatively simple optical technique. The approach selected has been configured for minimum cost. The primary is built from spherical segments which are all the same simplifying the manufacturing and test problem considerably. The basic approach, performing a center of curvature test, is a proven optical technique. A sunshade has intentionally been omitted to minimize cost. Heaters can be applied to individual segments to simulate thermal effects. The center of curvature sensor is an unsophisticated device. Details of this concept should be developed as soon as possible to assist in the formulation of an overall technology development plan.

The space station concept has not been "frozen" as of this date and the final selection may substantially differ from the baseline assumed for this study. We anticipate that, unless the SS concept is substantially smaller than that baseline, the dynamical impact of LDR will be small, as found in this study. The major issue of the SS configuration is a mitable assembly place for the LDR and the extent of additional structures for this assembly.

Contamination requirements of LDR and anticipated contamination levels at SS are both presently ill-defined and require for the study, in particular computer simulaton of Goth issues. The effects will depend strongly on the final concepts for both, LDR and space station.

Assembly sequences adn the relative proportions of EVA, robotics and automation are strongly LDR - design dependent. Therefore an early selection of the design should be planned.

Sunshade requirements depend on solar and earth limb exclusion angles. Comparison of the present baseline (60° sun; 45° earth limb) with others (e.g. 90° sun, 30° earth limb) indicate that the available observation time (sky access) depends less strongly on these requirements than Sunshade design.

In the long term these eleven missions which will utilize cryogens. These range from SIRTF which will require to Mission N S001 astronomy platform which will require 18 KG. of cryogen. Each refill offers the potential for doubling the payload life hence cryogenic transfer ishighly desirable. Current technology being developed for SIRTF should be well funded to insure the capability is available for the additional programs anticipated.

RECOMMENDATIONS

- FURTHER DEFINITION OF TDM
- CONTINUED UPDATE ON ASSEMBLY/SERVICING LOCATION (CHANGING SPACE STATION CONCEPT)
- CONTAMINATION: FURTHER STUDY
- ASSEMBLY AND ROBOTICS REQUIRE DETAIL STUDIES
- CRYOGEN TRANSFER REQUIRES DETAIL
- SUNSHADE DESIGN REQUIRES ADDITIONAL STUDY (EXCLUSION ANGLE DEPENDENCY - SIZE)